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# GUIDEBOOK

# GEOLOGY FIELD TRIP

# TO

# MONO/OWENS VALLEYS

October 6th and 7th, 1990

Mark Milliken

Sponsored By:

U.S. Bureau of Land Management
Bakersfield District Office
Bakersfield, CA

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U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

# Introduction

The eastern Sierra Nevada region contains some of the most spectacular and unique land forms in the United States. This region affords a great diversity in geology that attracts earth science students and scholars from around the world. They are drawn by textbook examples of volcanism, tectonics, glaciation, and valuable mineral deposits, all within a one day drive of Bishop.

The Bakersfield District of the Bureau of Land Management (Bob Rheiner, District Manager) is pleased to sponsor this and other field trips in central California. The BLM in California has a State office in Sacramento (Ed Hastey, State Director), and four Districts: Susanville, Ukiah, Bakersfield, and California Desert (see figure 1). Each District contains several Resource Areas. This weekend's field trip will be within the Bishop Resource Area (Mike Ferguson, Resource Area Manager). Please visit the Resource Area nearest you for more information on the resource values of California's Public Lands.

The road log is a mile-by-mile accounting of geologic features and planned stops along the field trip. The Appendix contains 1:250,000 scale maps of each segment of the trip showing our route. Also included in the Appendix is a USGS geologic time scale.

There is no cost for participating in the field trip. However there are minor incidental costs associated with the Guidebook and other aspects of the trip. We have therefore been authorized to accept tax deductible monetary contributions to help defray these costs. Although not required, a donation of $5.00 for the Guidebook would be greatly appreciated. Thank you very much.

We encourage any comments or recommendations on this or future field trips. Please contact:

U.S. Bureau of Land Management

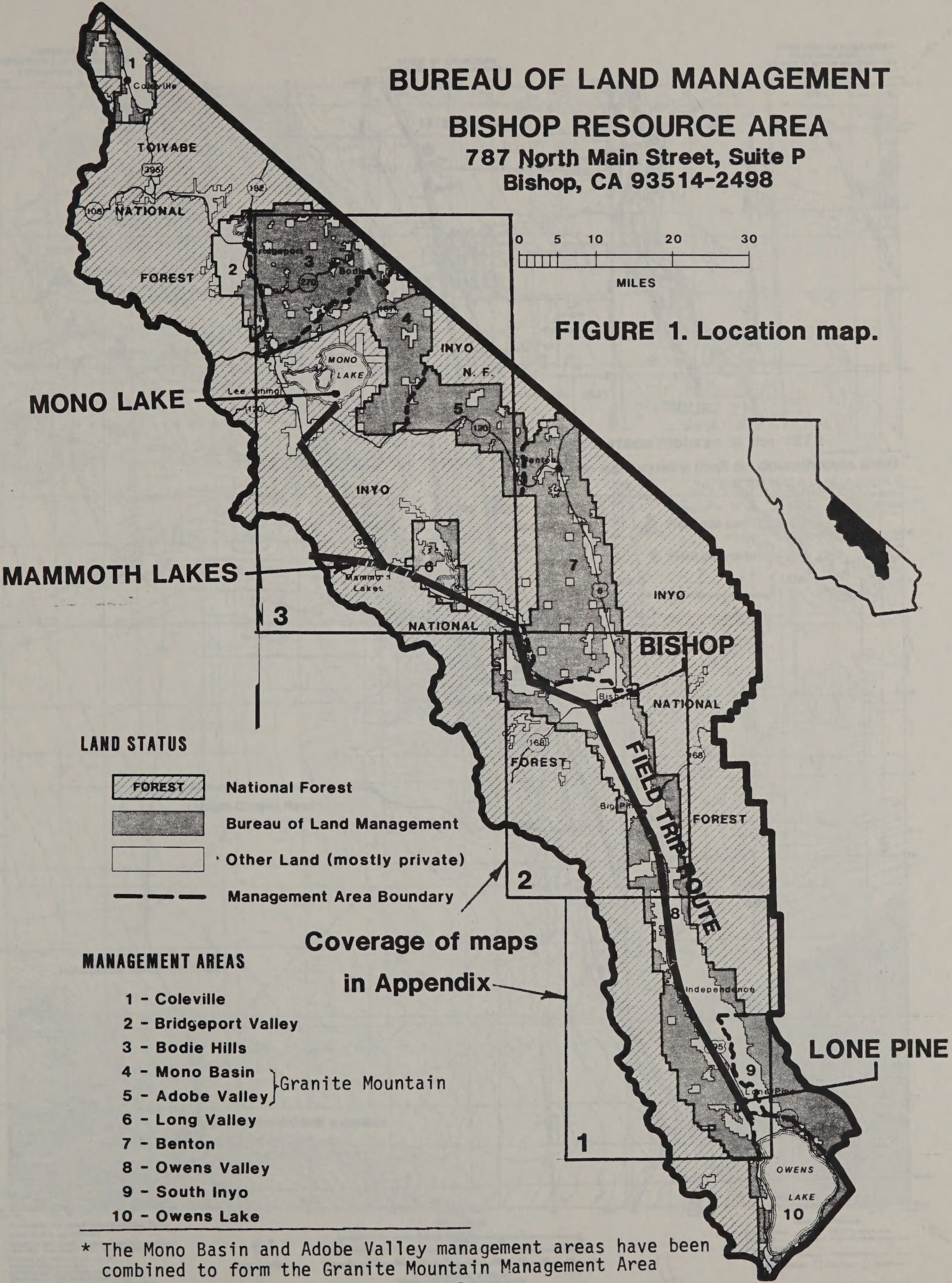
Bakersfield District Manager
800 Truxtun Ave.
Bakersfield, California 93301
(805) 861-4191
or,
Bishop Resource Area Manager
787 North Main St.
Bishop, California 93514-2498
(619) 872-4881

## BUREAU OF LAND MANAGEMENT

## BISHOP RESOURCE AREA

787 North Main Street, Suite P
Bishop, CA 93514-2498

FIGURE 1. Location map.



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* The Mono Basin and Adobe Valley management areas have been combined to form the Granite Mountain Management Area

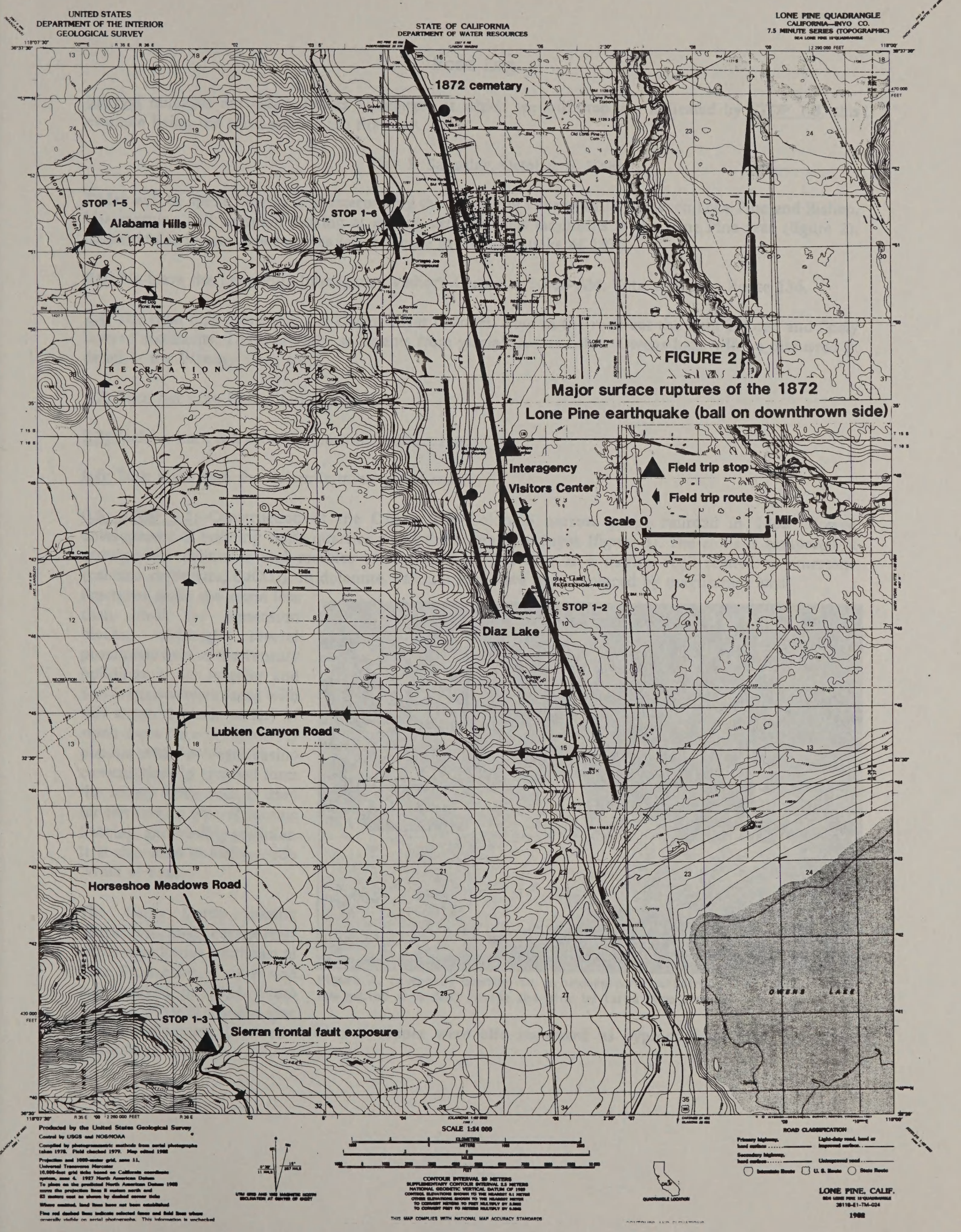


FIGURE 2

Major surface ruptures of the 1872 Lone Pine earthquake (ball on downthrown side)

# Road Log

Interval mileages are listed. Points of interest at which we will stop are indicated by STOP 1-3, this example being the third stop of the first day.

## Day 1: Saturday, October 6, 1990

Today will be spent viewing and interpreting the scenery of Owens Valley between Lone Pine and Bishop. The morning will be spent looking at mining activities and landforms in the Lone Pine area (figure 2). Of particular interest are features left from the great earthquake of 1872.

0.0: We leave the Lone Pine Interagency Visitor's Center at 10:00 AM. Turn east onto Route 136.

2.4: The road dips down into the Owens River channel. Note in the road cut the light colored and finely layered sediments. These are lake sediments from glacial Owens Lake. (Owens Lake will be discussed in detail at the Wonoga Peak stop).

1.2: Turn left onto Dolomite Loop road.

2.3: Make a hard left onto the northbound dirt road.

0.6: Turn right onto the dolomite mine access road.

0.5, STOP 1-1: Construction of the Carson and Colorado narrow gauge railroad in 1882 allowed development of building stone quarries along the base of the Inyos (figure 3). The stone is composed of snowy-white dolomites and marbles of Silurian age. Dolomite is a marine rock related to limestone (calcium carbonate, $CaCO_3$). In dolomite, calcium ions have been replaced by magnesium ions. Fractures make the stone less than ideal for dimension blocks, although several prominent turn of the century buildings in Los Angeles and San Francisco were faced with this stone. A black variety of stone from here is reportedly popular with Las Vegas casino construction. In crushed form the snowy white rock is used for terrazzo, a type of mosaic flooring, and roofing granules. It is also used in Hollywood's "Walk of Fame."

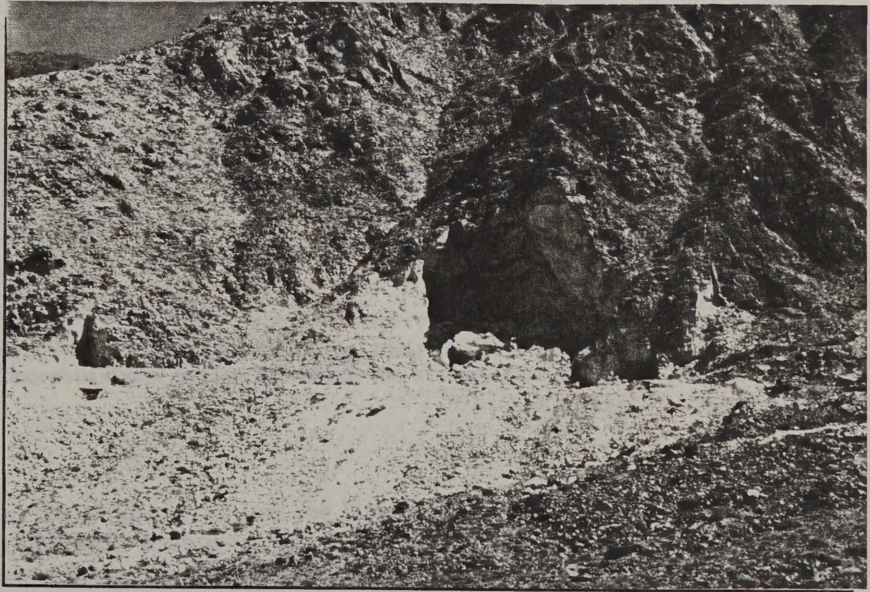


**Figure 3.** Cavernous opening to an underground building stone quarry. Stone was hauled from deep inside the mine by large dump trucks.

The Cerro Gordo mining district is located near the crest of the Inyo Range southeast of here. Production of silver and lead peaked in 1874. From 1911 to 1919 carbonate zinc was an important product. Gold and copper were also recovered as byproducts of lead and silver extraction.

Some remains are still left of a remarkable 13 mile tram built in 1912. Originating in Swansea, it crossed the Inyos to Saline Valley where salt was mined and transported back to a mill at Swansea. Workmen were transported to Saline Valley in tram buckets. Antique hunters attempting to disassemble the tram face prison time, for much of the remains are within a wilderness study area.

To the west we see a sweeping panorama of Owens Valley and the eastern Sierra Nevada range. The Owens Valley, like many basin and range valleys, is a fault-bounded, down-dropped block containing a closed depression (Owens Lake). In fact, the eastern Sierran escarpment including Mt. Whitney may be construed as a huge, deeply eroded normal fault scarp or family of faults extending from Lake Tahoe in the north to the Garlock Fault in the south. As we will see later these faults commonly represent zones of weakness through which volcanic rocks from deep within the earth were extruded.

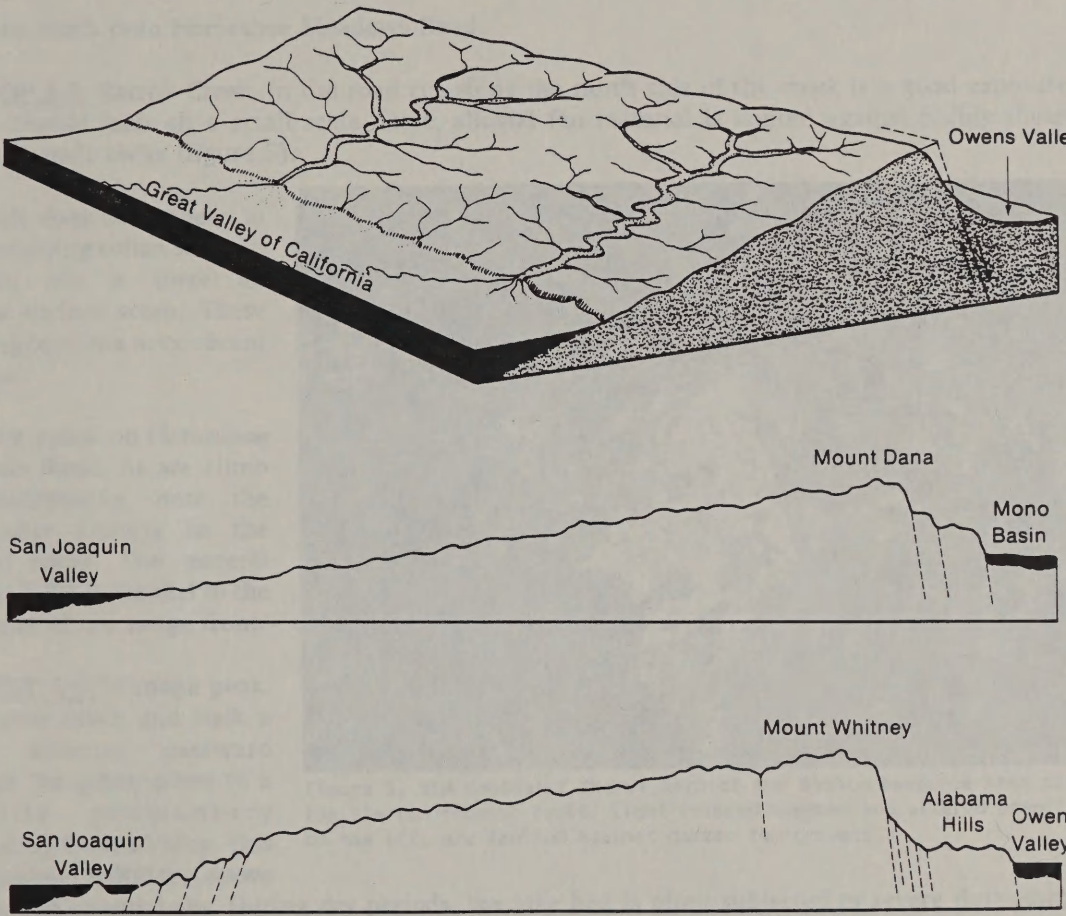


**Figure 4.** Generalized diagrams of the Sierra Nevada Range. The range is a westward-tilted block of granites and older metamorphic rocks as roof pendants. The Alabama Hills were, at one time, even with Mt. Whitney.

That the Sierras are still rising is evidenced by fresh fault scarps all along the base of the escarpment and ongoing earthquake activity. The tragic 1872 Lone Pine earthquake was accompanied by severe ground shaking and significant vertical and horizontal ground displacements. The Alabama Hills are part of the Sierran block that failed to be elevated (figure 4).

6.6: Return to the intersection of US 395 and Route 136, and turn south onto 395.

1.3: Turn into the Lake Diaz recreation area and proceed around to the east side of the lake.

0.5, STOP 1-2: View of the west-facing 1872 fault scarp that forms the eastern shore of Lake Diaz. The main fault split north of Lake Diaz into this west-facing branch and an east-facing branch that forms the western shore (figure 2). The resulting depression was filled with ground water and Lake Diaz was born. Return to US 395 southbound.

1.3: Turn west onto Lubken Canyon Road.

3.4: Turn south onto Horseshoe Meadows Road.

2.9, STOP 1-3: Carroll Creek. In the road cut along the north side of the creek is a good exposure of the Sierran frontal fault on a small scale. Here, alluvial fan material is faulted against highly sheared and altered granitic rocks (figure 5).

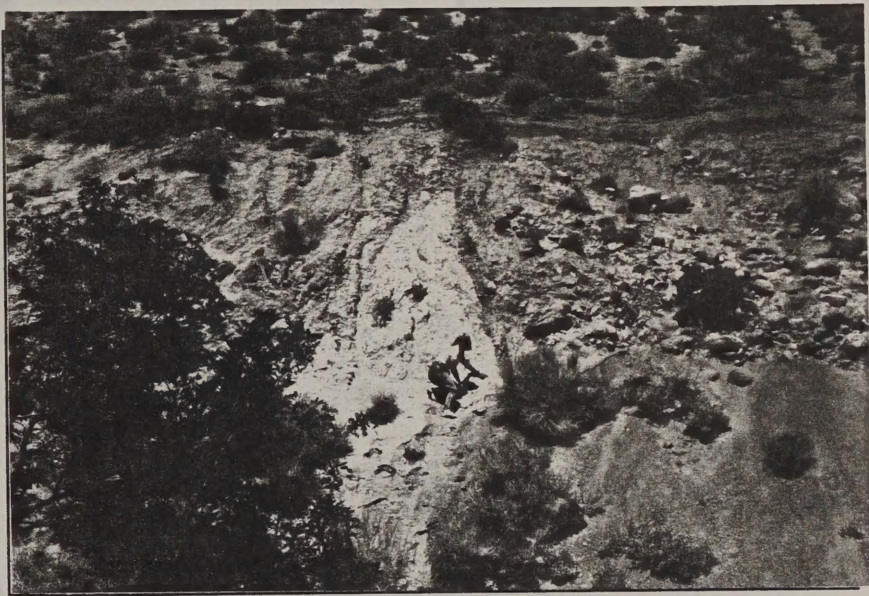


Figure 5. BLM Geologist Cheryl Seth of the Bishop Resource Area points out the Sierran frontal fault. Light colored sheared and altered granitic rocks on the left are faulted against darker fan gravels.

The fault does not appear to offset overlying eolian surficial deposits, nor is there an obvious surface scarp. These clues suggest little or no recent slippage.

Continue south on Horseshoe Meadows Road. As we climb the switchbacks, note the spectacular jointing in the granitic rocks. The general jointing habit is parallel to the NW trend of the range front.

7.3, STOP 1-4: Wonoga peak. Bring your lunch and walk a short distance eastward through the piñon pines to a granitic promontory overlooking Owens Valley. This point is about 6,000 feet above the floor of Owens Lake. During dry periods, the lake bed is often subjected to severe dust storms, with health-threatening particulates traced 250 miles south (St. Amand, 1987). The red color in the brine pools is due to algae and bacteria. In the late 1800s the lake was 30 feet deep. Indeed, steamboats hauled Cerro Gordo ore across the lake from Keeler to near Olancha. The loss of recharge water through climate change, irrigation, and diversion to Los Angeles resulted in a dry lake by 1926. Over 350,000 acre-feet of water are now exported annually.

The playa surface is generally hard in the summer and soft during wet periods. Wells drilled through the sediments of the playa (one well penetrated nearly 7,000 feet without reaching bedrock) have yielded a continuous series of clays and silts with no substantial evaporite (salt) layers. No salt at depth means the lake has never been dry for long periods of time. In contrast, Lake Searles exhibits great thicknesses of evaporites. Owens Lake playa contains sodium chloride, carbonate, sulphate, and minor amounts of borates, nitrates, potassium, and lithium (St. Amand, 1987). Soda minerals, primarily trona and natron, have been mined from the playa. Operations at Keeler yielded sodium carbonate used in China for making china. Directly below is Bartlett Point where, from the late 1920s through the 1950s, the Pittsburgh Plate Glass Company recovered borax from evaporation ponds.

During the ice ages, Owens Lake was filled to the 3,880 foot elevation. This prominent shoreline is best displayed along the southern margin of the lake. The northern extent of the lake would have been near Independence. Glacial meltwater from receding Pleistocene Sierran glaciers filled several eastern California basins to overflowing, causing a chain of lakes between Mono Basin (ancestral Lake Russell) and Death Valley (ancestral Lake Manley). large lakes filled valleys in between (figure 6).

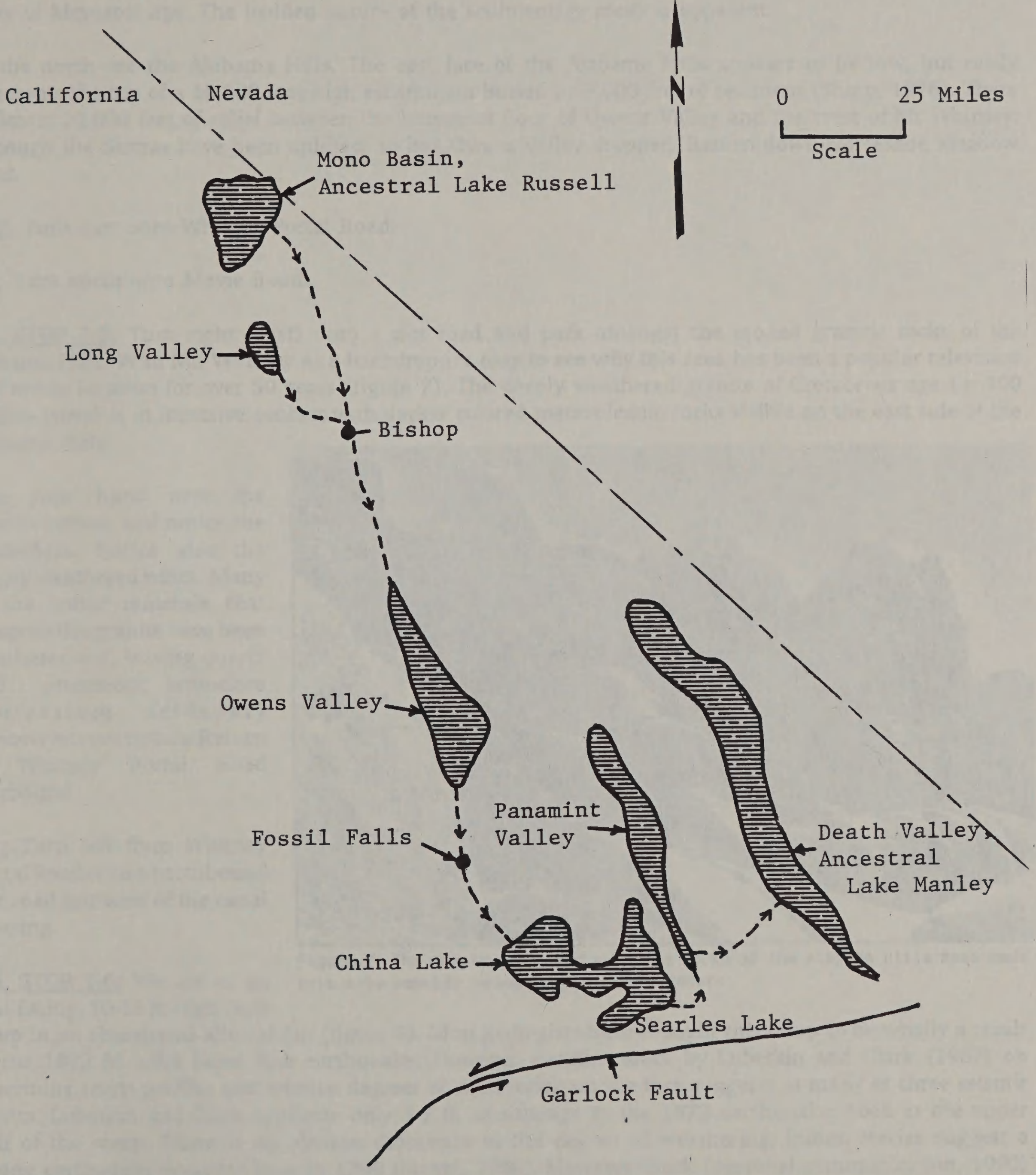


**Figure 6.** Meltwater from Pleistocene alpine glaciers in the Sierra Nevadas filled many of the structural lows within the "basin and range" province. The lakes overflowed, creating streams now abandoned.

Streams, sometimes of great capacity, connected the valleys. The ancestral Owens River flowed south through Fossil Falls on its way to China Lake during very wet periods of the Pleistocene when Owens Lake overflowed. Flow south of Owens Lake through Fossil Falls ceased 3,500 to 4,000 years ago (St. Amand, 1987).

The Inyo Mountains look very different from the Sierras on which we stand. The rocks of the Inyos are mostly sedimentary in composition and Paleozoic in age. Also included are intrusive and metavolcanic rocks of Mesozoic age. The bedded nature of the sedimentary rocks is apparent.

To the north are the Alabama Hills. The east face of the Alabama Hills appears to be low, but really represents the top of a 10,000 foot high escarpment buried by 9,000 feet of sediment (Sharp, 1976). There is almost 20,000 feet of relief between the basement floor of Owens Valley and the crest of Mt Whitney. Although the Sierras have been uplifted, so has Owens Valley dropped. Return down Horseshoe Meadow Road.

13.7: Turn east onto Whitney Portal Road.

0.4: Turn north onto Movie Road.

0.5, STOP 1-5: Turn right (east) onto a dirt road and park amongst the eroded granitic rocks of the Alabama Hills. With Mt. Whitney as a backdrop it's easy to see why this area has been a popular television and movie location for over 50 years (figure 7). The deeply weathered granite of Cretaceous age (± 100 million years) is in intrusive contact with darker colored metavolcanic rocks visible on the east side of the Alabama Hills.

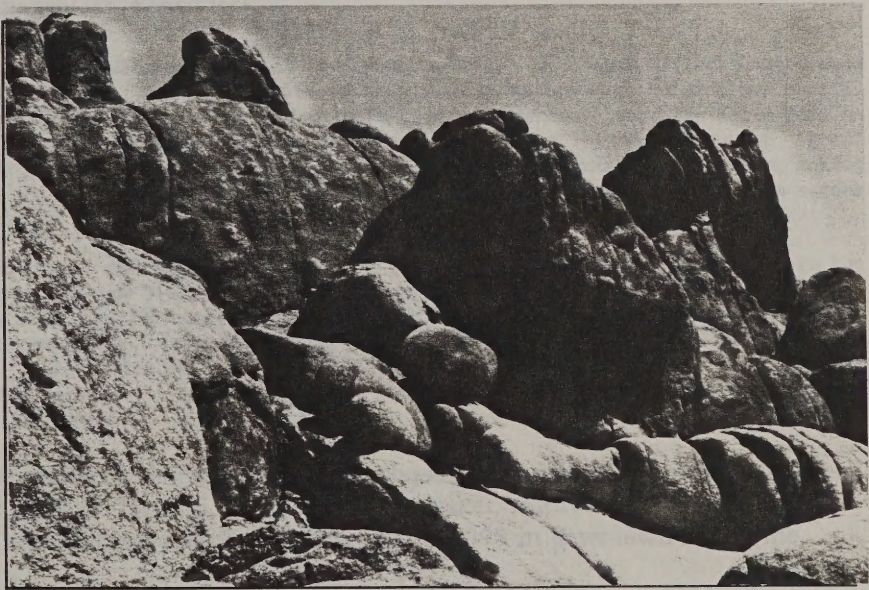


Figure 7. The deeply weathered granitic rocks of the Alabama Hills have made this area popular among western movie makers.

Run your hand over the granite surface and notice the coarseness. Notice also the deeply weathered joints. Many of the softer minerals that compose the granite have been weathered out, leaving quartz and prominent orthoclase (potassium feldspar) phenocrysts or crystals. Return to Whitney Portal Road eastbound.

2.1: Turn left from Whitney Portal Road onto a northbound dirt road just west of the canal crossing.

0.6, STOP 1-6: We are at an east-facing, 10-15 ft. high fault scarp in an abandoned alluvial fan (figure 8). Most geologists have thought this scarp to be wholly a result of the 1872 M ±8.3 Lone Pine earthquake. However, detailed work by Lubetkin and Clark (1987) on describing scarp profiles and relative degrees of weathering on the face suggests as many as three seismic events. Lubetkin and Clark attribute only 3-7 ft. of slippage to the 1872 earthquake. Look at the upper half of the scarp. There is an obvious difference in the degree of weathering. Indian stories suggest a strong earthquake occurred here in 1790 (Iacopi, 1980). However Clark (personal communication, 1990) has not confirmed such an event.

The 1872 Lone Pine earthquake was as great or greater in intensity than the 8.3 San Francisco earthquake of 1906. Indeed, Lone Pine may be the most severe California earthquake in recorded history. Some 27 people were killed and many more were injured. The dead were buried in a mass grave on top of the 1872 fault scarp about one mile north of Lone Pine. The casualties represented a large proportion of the Lone Pine population at that time. Most of the casualties resulted from collapsing adobe and stone houses. Wood frame structures were less damaged.

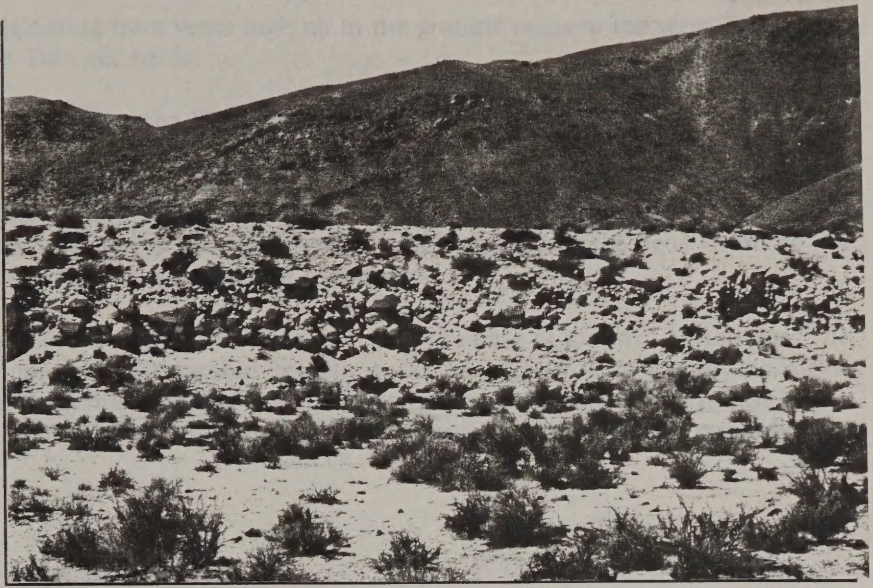


**Figure 8.** 1872 fault scarp in an alluvial fan west of Lone Pine. The shape of the scarp face suggests at least three separate seismic events. Offset during the 1872 earthquake was 3-7 ft.

The earthquake was felt as far away as Ely, Nevada and Los Angeles. Rockfalls were witnessed in Yosemite Valley, 85 miles away. John Muir was an eyewitness:

> "It was a calm moonlit night, and no sound was heard for the first minute or so, save low, muffled, underground bubbling rumblings, and the whispering and rustling of agitated trees, as if Nature were holding her breath. Then, suddenly, out of the strange silence and strange motion there came a tremendous roar. The Eagle Rock on the south wall, about a half mile up the valley, gave way and I saw it falling in thousands of the great boulders I had so long been studying, pouring to the valley floor in a free curve luminous from friction, making a terribly sublime spectacle - an arc of glowing passionate fire, 1,500 ft. span, as true in form and as serene in beauty as a rainbow in the midst of the stupendous, roaring rock-storm...
>
> "The first severe shocks were soon over, and eager to examine the new-born talus I ran up the valley in the moonlight and climbed upon it before the hugh blocks, after their fiery flight, had come to complete rest. They were slowly settling into their places, chafing, grating against one another, groaning, and whispering. But no motion was visible except in a stream of small fragments pattering down the face of the cliff. A cloud of dust particles, lighted by the moon, floated out across the whole breadth of the valley, forming a ceiling that lasted until after sunrise, and the air was filled with the odor of crushed Douglas spruces from a grove that had been mowed down and smashed like weeds."

Envicom (1976) predicts a 5,000 year recurrence interval for earthquakes the same size as the 1872 event. They predict 100 and 500 year intervals for M 5.25 and 6.5 earthquakes, respectively.
Return to Whitney Portal road and proceed east. Turn north onto US 395 in downtown Lone Pine.

1.0: On the west side of US 395 is the 1872 fault scarp, here about 20 feet high. A roadside marker points out the mass grave of the 27 victims of the 1872 earthquake.

1.0: The 1872 fault scarp continues northerly on the west side of US 395. It swings west and can been seen at the base of the Alabama Hills (don't confuse the canal with the fault scarp).

2.5: The 1872 fault scarp swings northeast and crosses the highway here.

18.5: We are entering the Big Pine volcanic field. Fresh cinder cones along each side of the valley are located on faults. Lava flows from these fissures have flowed down onto the valley floor.

1.5: US 395 crosses lava flows originating from vents high up in the granitic rocks to the west. These lava flows make good habitat for local Tule elk herds.

9.0: Turn right from US 395 into the Tinemaha Wildlife Viewpoint.

1.0, STOP 1-7: Follow signs to the parking area on the hill to the north. Walk out to the viewpoint. Tinemaha reservoir is a holding tank for water going to Los Angeles. The hill we are on is an uplifted block of lake bed sediments, possibly related to the gently west-dipping Waucoba Lake Beds visible to the north. A black bouldery basalt flow lies atop some of the sediments.

To the southeast are basaltic cinder cones and flows emanating from the base of the Inyo Mountains. The Poverty Hills to the west are composed of Cretaceous granitic rocks and Paleozoic metamorphic rocks. There has been some mining interest in this area, but to date no known commercial mines. The "New Era" mine can be seen across US 395, where attempts are being made to extract platinum from groundwater.

To the northwest can be seen Crater Mountain, several fresh faults, and a faulted cinder cone. Crater Mountain is a basaltic volcano perched atop a granitic hill (figure 9). Parts of the underlying granitic hill pop out from beneath the lava as islands. The largest "island" is Fish Spring Hill where numerous mining operations have scarred the hillside. We now return to US 395 northbound.

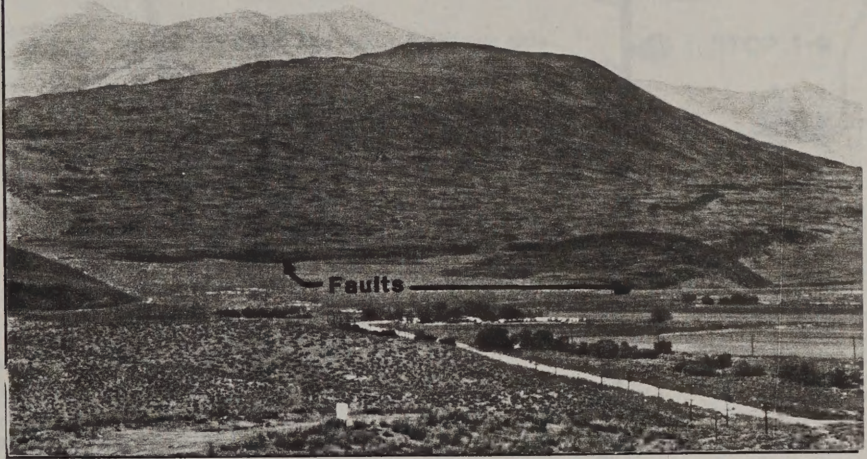


**Figure 9.** Crater Mountain is a volcano rising 2,000 feet above Owens Valley. But looks can deceive. The basaltic vent and flows are perched atop a ±1,200 foot high granitic hill. The dark linear lines near the base are faults.

1.1: Turn left from US 395 onto Fish Springs Road.

0.5: Turn left onto Tinemaha Road. Stay on the paved road, continuing through the campground (see figure 10).

3.7, STOP 1-8: Perlite mine overlook. The hill immediately to the west is composed of perlite, a hydrous form of a volcanic rock called rhyolite. You've noticed the basalt flows of the Big Pine volcanic field. Basalt has a low viscosity and flows freely, because its chemical composition is low in silica. Rhyolite, high in silica, is high in viscosity and squeezes out of the earth, like toothpaste out of a tube, into local domes.

American Perlite mines about 50,000 tons of rock annually. The ore is crushed to sand-sized particles and shipped to processing plants to be heated and popped like popcorn. Its expansive qualities make it good for uses including absorbant and dehydrator, soil additive, lightweight concrete, insulation, paint fillers, stucco, ceiling and roofing material, tile cleaner, and cattle feed supplement.

Figure 10 is a map showing some notable features of this area. Figure 11 is an oblique areal photo that clearly shows the relationships between faults and cinder cones that we will examine.

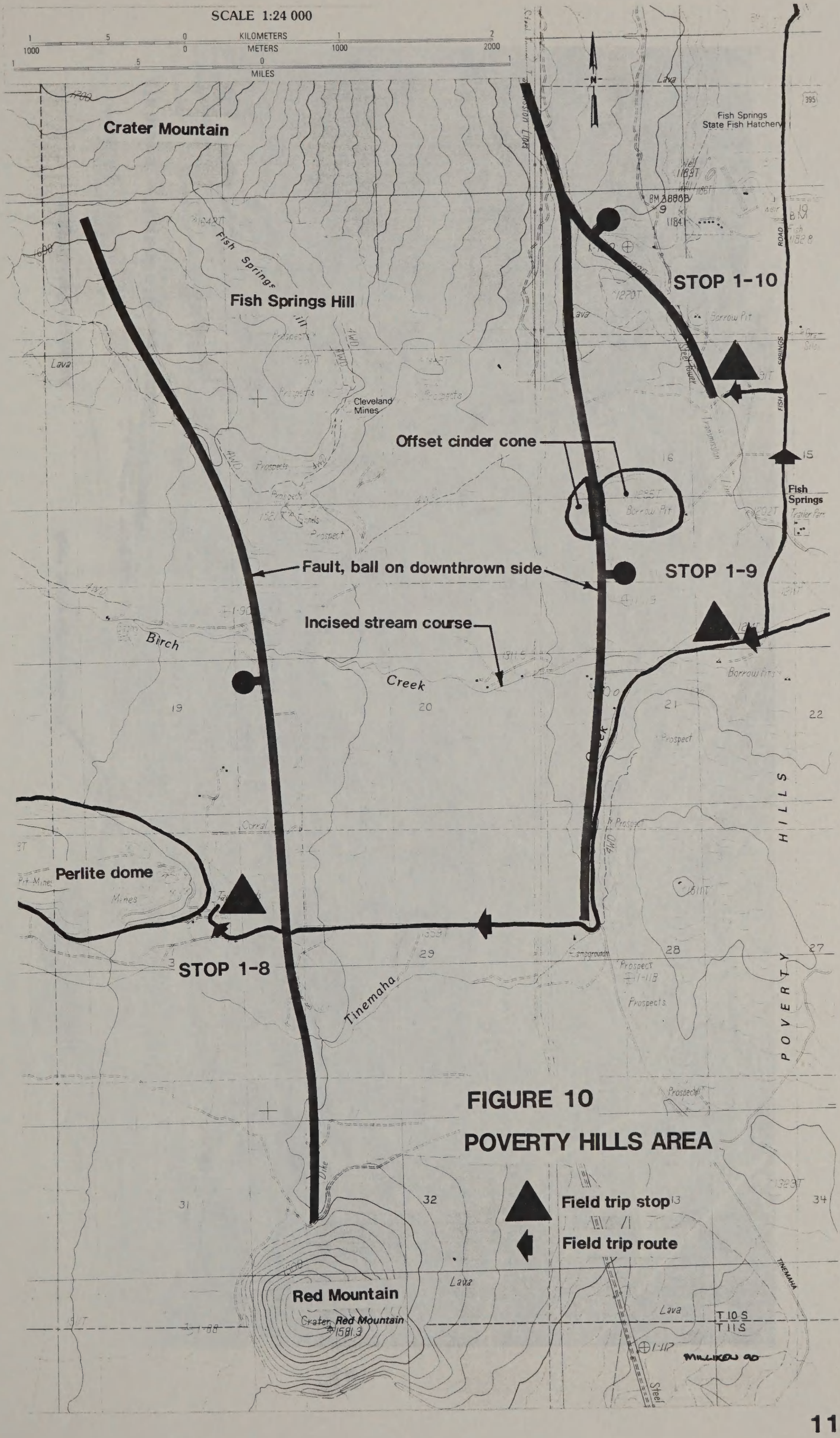
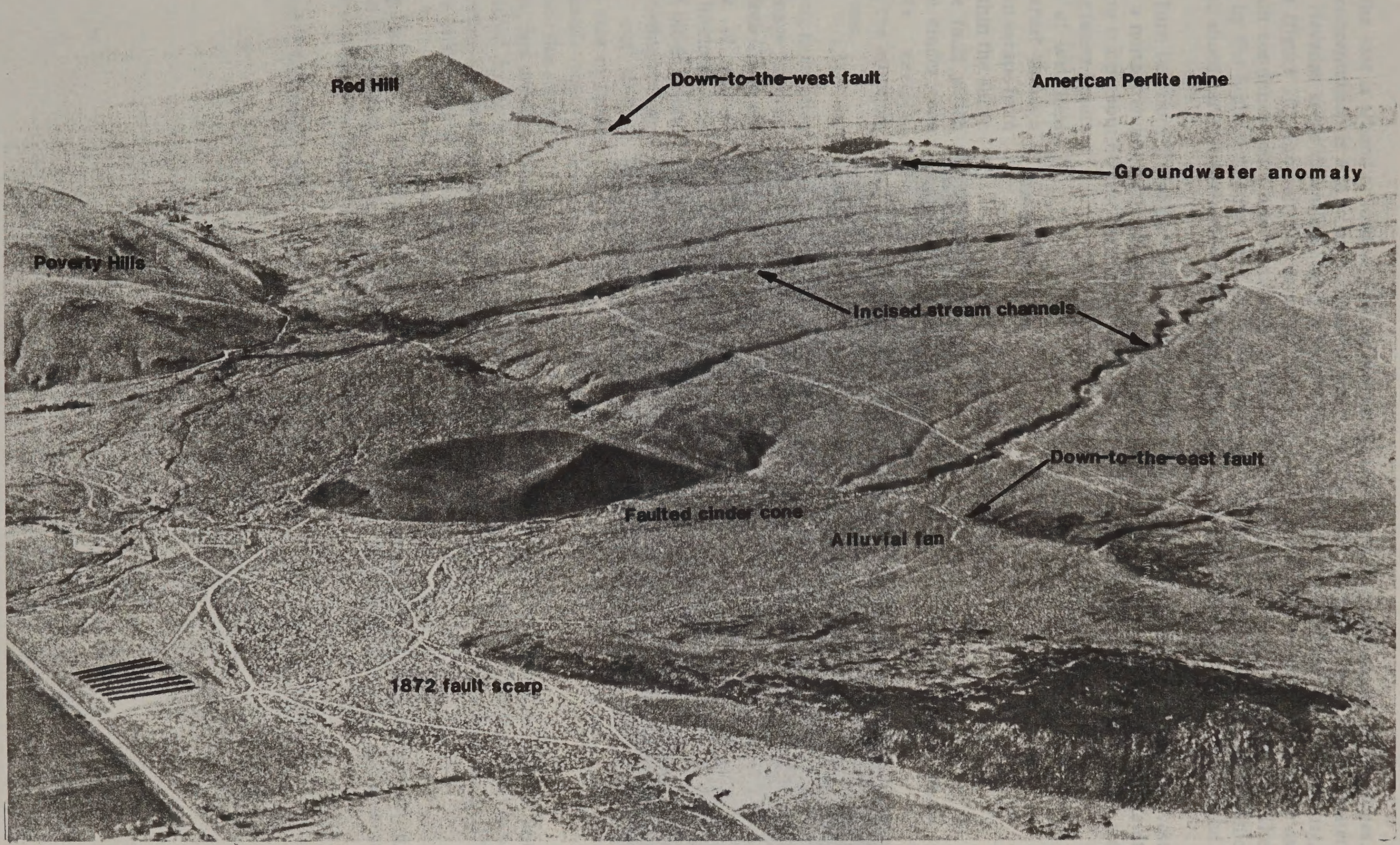


FIGURE 10

POVERTY HILLS AREA

Figure 11. Poverty Hills area looking southwest.



Immediately to the east is a band of lush vegetation that seems out of place on the semi-arid fan slopes. The vegetation concentration is due to an anomalous wet area (figure 11) behind a fault. Groundwater from the Sierra Nevadas seeps downslope until it reaches an impasse at the prominent north-trending, west-facing fault (figure 10). Groundwater dams up behind the fault, eventually reaching the surface as springs. This fault continues south and terminates at Red Hill, a basaltic cinder cone (figure 10). The cone is not cut by the fault, indicating that the cone is younger. Quite possibly, the Red Hill volcanic eruption occurred shortly after the seismic event associated with the fault. Return back on Tinemaha Road.

**3.3, STOP 1-9:** Turn left from Tinemaha Road onto a northbound paved road and stop. Off to the west about 3/4 mile, a north trending fault offsets a cinder cone in spectacular fashion (figure 12). This fault has an east facing scarp about 60 feet high (figure 11). As we saw earlier with Red Hill, cinder cones are often found along faults. Faults represent zones of weakness in the earth's crust through which magma can escape from sources deep within the earth. In this case the fault which gave rise to the cinder cone continued its vertical movement after the eruption, and offset the cone.

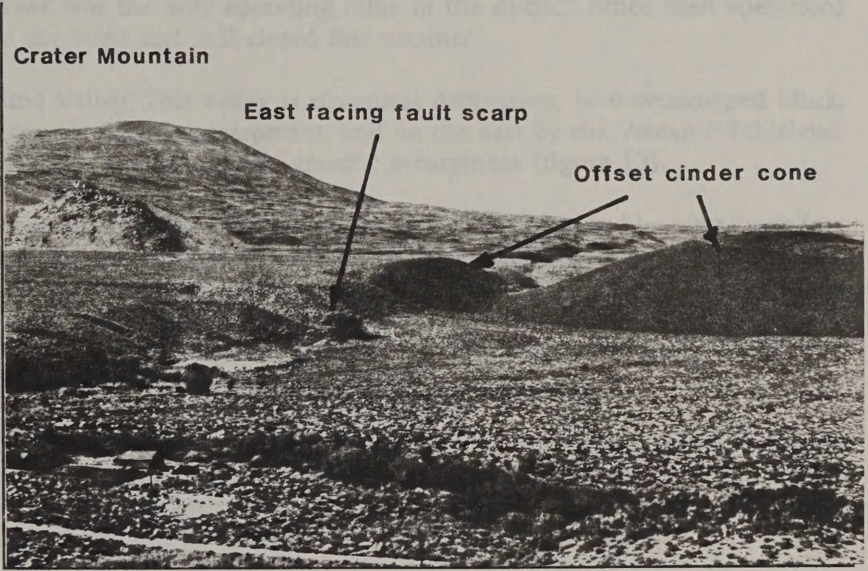


**Figure 12.** Offset cinder cone along a fault north of the Poverty Hills. The cone has been offset about 60 feet.

Displacement along faults often effects local drainage patterns. Tinemaha and Birch Creeks are good examples of incised streams on fault blocks (figures 10 and 11). As a block of land is uplifted, pre-existing streams on the block cut deeper channels. If the rate of uplift exceeds the stream's capacity to cut its channel, the stream may be forced to find another course. Birch Creek has successfully managed to maintain its channel and construct an alluvial fan as it passes through the east facing fault scarp (figure 11). This fault continues northward, offsetting basalt flows on the east flank of Crater Mountain (figure 9). To the south, the fault's surface exposure terminates at Tinemaha Campground. Continue northbound.

**1.3, STOP 1-10:** Pull over to the side of the road. This spot affords a good view of Crater Mountain, its basalt flows, and faults along its eastern flank. The very fresh appearing fault that offsets lava flows about ¼ mile from us is shown by Sharp (1976) to be an 1872 rupture.

This stop completes Saturday's tour.

## Day 2: Sunday, October 7, 1990

**0.0:** Today's tour leaves the Vagabond Motel at 8:00 AM. Proceed northbound on US 395.

**7.0:** About two miles to the southeast of US 395 are some low hills with substantial workings apparent. These are the Tungsten Hills, aptly named for the metallic deposits found there. With the first discoveries made about 1913, the Bishop tungsten district evolved into one of the premier producing areas of the U.S. The demand for tungsten is dependant on whether the U.S. is at war. Production from the Pine Creek mine, one of the largest tungsten mines in the U.S., began in 1918. Tungsten demand was high due to WW I. The market collapsed after WW I and production ceased. Demand again increased in the 1930s. Peak tungsten production occurred during WW II when the U.S. government fixed prices, followed by a market collapse. Korea resulted in increased demand in the early 1950s, to be followed by yet another market collapse. By 1958 Pine Creek was the only operating mine in the district. Since then operations have been on a limited scale, and the mine and mill closed this summer.

We are now descending into Round Valley. This valley is structural depression, or downdropped block, bounded on the west by the spectacular Sierran escarpment, and on the east by the Volcanic Tableland. Fresh fault scarps cut alluvial fans along the base of the granitic escarpment (figure 13).

**12.7, STOP 2-1:** Pull into the viewpoint parking area. We are on the Volcanic Tableland looking down into Round Valley. About 730,000 years ago, the Long Valley caldera collapsed, accompanied by a cataclysmic volcanic eruption (Bailey, 1989). The resulting ash falls and incandescent ash flows formed the Bishop Tuff. The Bishop Tuff covered a large area around the caldera, primarily to the southeast (figures 13 and 14). The tuff is found buried in Owens Valley at least eight miles south of Bishop at depths of 700 feet. Tuff outcrops are found as far north as the Mono Basin.

Bishop Tuff is composed of a lower air fall pumice layer and an upper "welded" layer. The welded layer resulted from a very hot and fast moving "fiery cloud." Another term commonly used for this type of eruption is "nuée ardente." Temperatures were high enough to melt glass. Individual mineral grains were welded together, forming a relatively hard and brittle rock.

Local warping of the land surface here has caused folding and faulting of the Bishop Tuff. Pleistocene Long Valley Lake formed as the Volcanic Tableland was uplifted, blocking drainage out of Long Valley. Eventually the lake overflowed and carved the Owens River Gorge. The Bishop Tuff is intensely faulted by curvilinear normal faults trending NNW. (figure 13). Being very brittle, the tuff resists bending or folding, preferring to break. These faults are characteristic of the Volcanic Tableland and locally control drainage. Fish Slough is an example of a fault controlled stream.

| Glaciation | Age (years) |
|---|---|
| Neoglacial | 2-3,000 |
| **Tioga** | **10-20,000** |
| Tenaya | 25-40,000 |
| **Tahoe** | **60-130,000** |
| Mono Basin | 87,000 |
| Donner Lake | 250,000 |
| **Casa Diablo** | **400-500,000** |
| **Sherwin** | **750,000** |
| **McGee** | **2.5-3.2 million** |

**Table 1.** Major Sierran glaciations. Those referred to in this report are highlighted. Ages are from Malcolm Clark, USGS, Personal Communication, 1990

The spectacular Sierran escarpment dominates the western and southern views. To the south we see Pine Creek and the prominent glacial lateral moraines emanating from the valley. These well-preserved moraines of Tahoe and Tioga age (see table 1) are present in most canyons along the Sierra Nevada front northward to Truckee and beyond.

**1.7:** Sherwin Summit. Turn right from US 395 onto an eastbound dirt road (figure 15).

**2.5:** LADWP surge tank. Here the roads forks into three directions; take the middle fork.

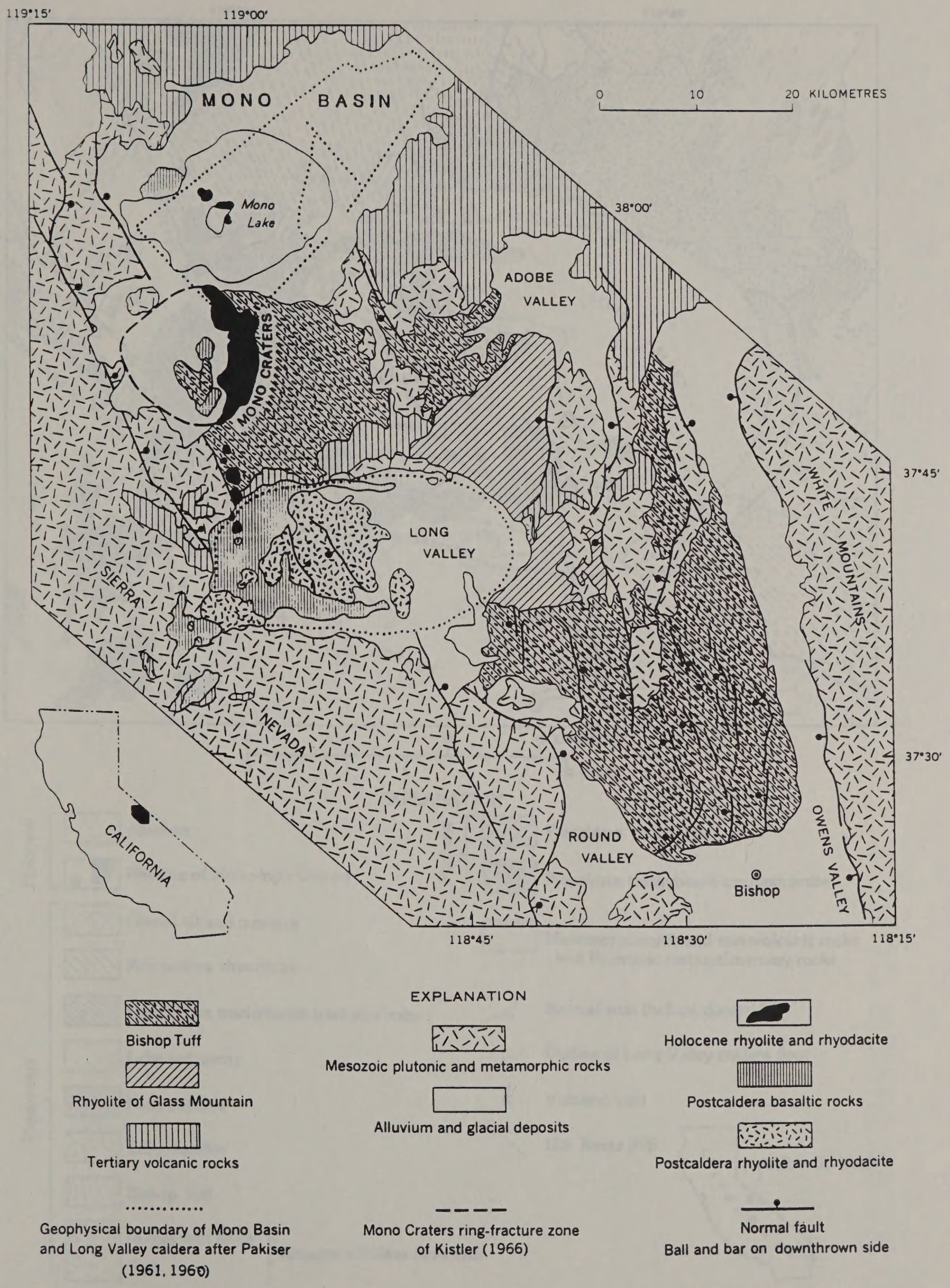

119°15'
119°00'
MONO BASIN
Mono Lake
MONO CRATERS
ADOBE VALLEY
LONG VALLEY
SIERRA NEVADA
WHITE MOUNTAINS
ROUND VALLEY
OWENS VALLEY
Bishop
CALIFORNIA
0 10 20 KILOMETRES
38°00'
37°45'
37°30'
118°45'
118°30'
118°15'
EXPLANATION
Bishop Tuff
Rhyolite of Glass Mountain
Tertiary volcanic rocks
Mesozoic plutonic and metamorphic rocks
Alluvium and glacial deposits
Holocene rhyolite and rhyodacite
Postcaldera basaltic rocks
Postcaldera rhyolite and rhyodacite
Geophysical boundary of Mono Basin and Long Valley caldera after Pakiser (1961, 1966)
Mono Craters ring-fracture zone of Kistler (1966)
Normal fault
Ball and bar on downthrown side

**Figure 13. Geologic map of the Long Valley–Mono basin area (from Bailey, 1989).**

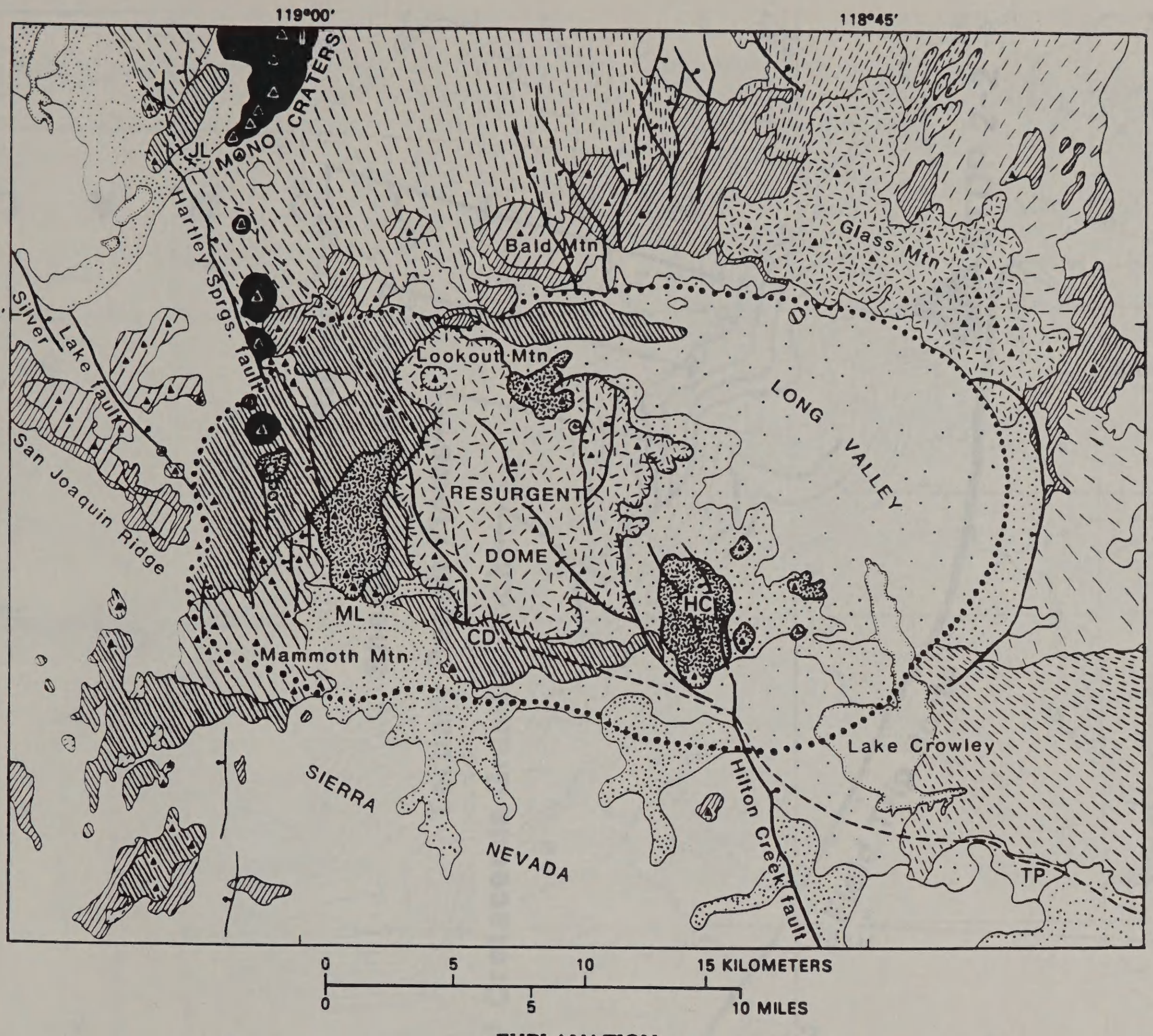
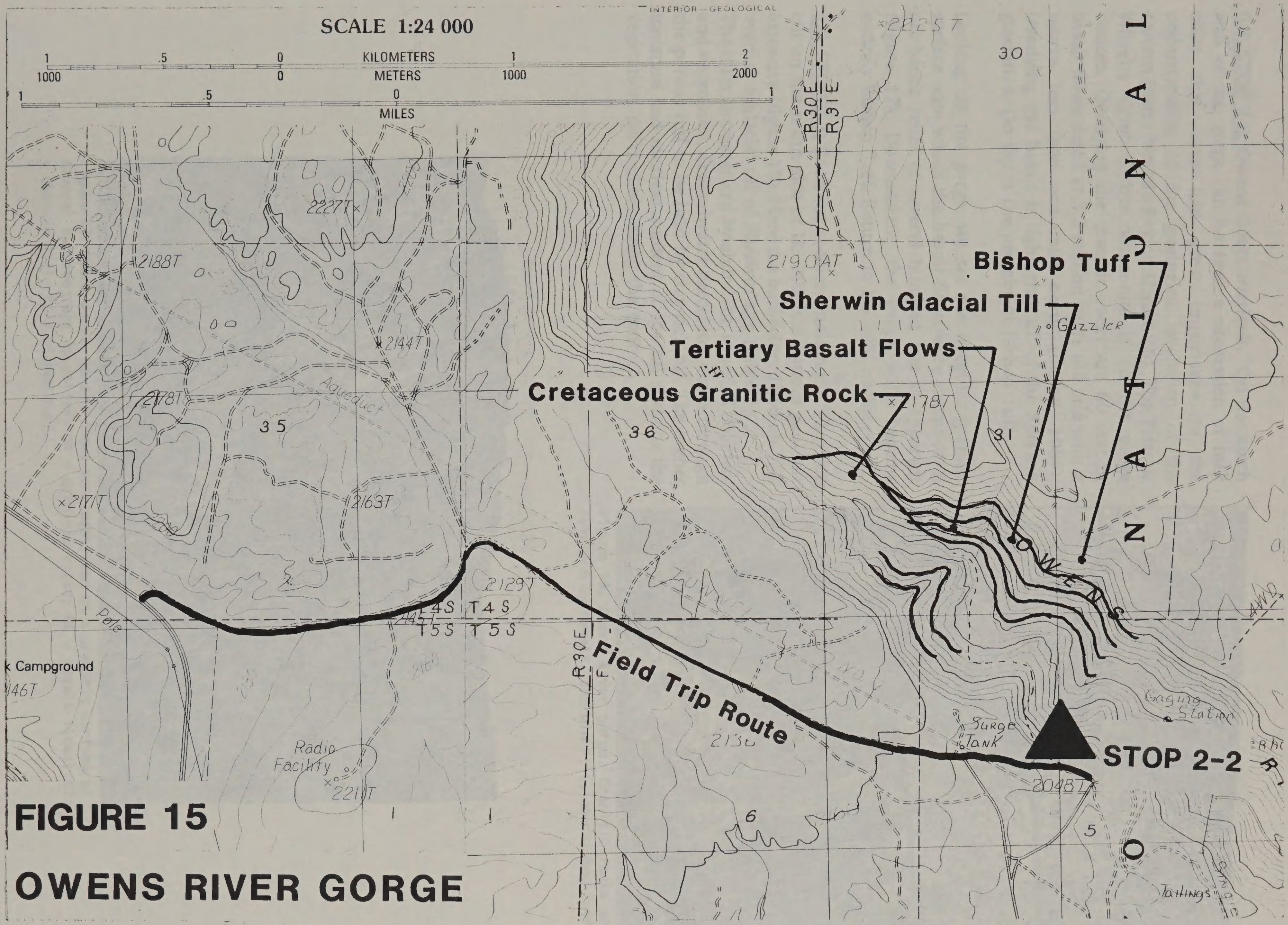


**Figure 14. Geologic map of the Long valley caldera (from Bailey, 1989).**



## FIGURE 15

## OWENS RIVER GORGE

0.3, STOP 2-2: Owens Gorge overlook. On the north wall of the gorge can be seen a succession of rock units that have had great importance to the understanding of the geological evolution of the eastern Sierra Nevada Region (figure 16). The Triassic Wheeler Crest Quartz Monzonite is on the gorge bottom. Overlying the granitic rocks are 60 feet of basalt flows dated at 3.2 million years old and with a source less than one mile north (Bailey, 1989). Overlying the basalt is light gray till of the Sherwin glaciation. On top is the prominent Bishop Tuff.

Looking up the gorge, we see the irregular granitic surface onto which the basalt flows were extruded. A pre-basalt relief of several hundred feet is apparent (figure 17). Downstream, the gorge walls become entirely Bishop Tuff. Return to US 395, northbound.

1.0, STOP 2-3: Road cut at Sherwin Summit. The road cut on the north side of US 395 is a famous geologic exposure (figure 18). Here the buff-colored Bishop Tuff overlies a glacial till of Sherwin age (table 1).
The till is characterized by abundant, rounded boulders and vegetation. Groundwater percolates down through the porous tuff to be held by clay-rich till. The higher moisture and nutrient content of the till sustains the vegetation, particularly along the contact.

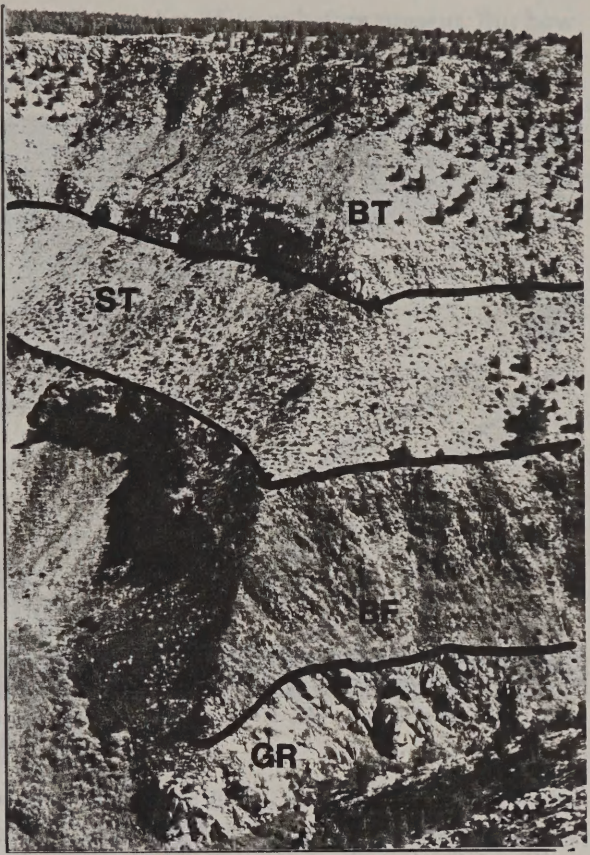


**Figure 16.** Owens River gorge. Granitic rocks are overlain by basalt, Sherwin Till, and Bishop Tuff.

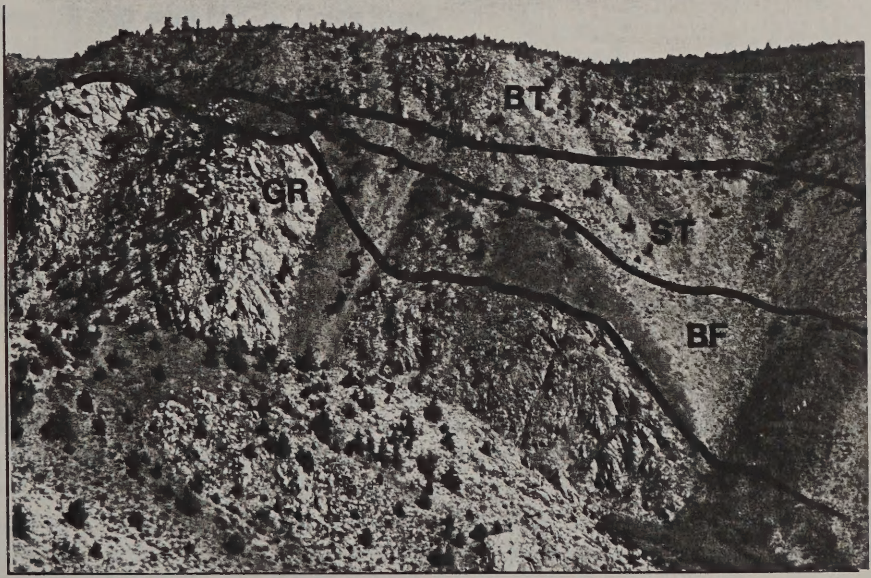


**Figure 17.** Owens Gorge. Basalt flows were deposited on a granitic surface of several hundred feet in relief. GR = granitic rocks; BF = basalt flows; ST = Sherwin Till; BT = Bishop Tuff.

Table 1 gives absolute ages for Sierran glacial tills, i.e., a specific number of years before present. But how do we know that the till we are looking at is 750,000 years old?

Tills younger than 40,000 years can be dated by $\text{Carbon}^{14}$ analysis of organic material ($\text{Carbon}^{14}$ transforms to $\text{Nitrogen}^{14}$ over a half life of 5,600 years). So Tahoe and older tills must be indirectly dated by comparing them to adjacent volcanic rocks which we can accurately date.

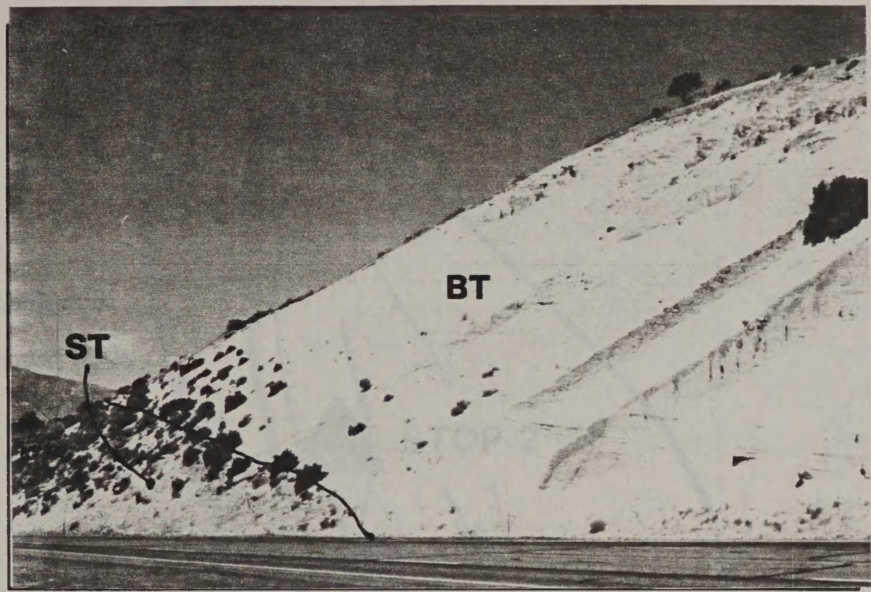


**Figure 18.** The famous Sherwin Summit roadcut on US 395 where Bishop Tuff (BT) overlies darker Sherwin Till (ST).

All volcanic rocks contain $\text{Potassium}^{40}$ (K). As with Carbon/Nitrogen, Potassium transforms to its daughter element, $\text{Argon}^{40}$ (Ar). The K/Ar half life is 1,470,000,000 years, meaning much older rocks can be dated. So to date a volcanic rock we look at how much Potassium is left. Knowing the rate at which Potassium decays, we can then compute the absolute age of the rock.

If, as we saw at Owens Gorge, a till is sandwiched between two volcanic flows, we can date the flows by the K/Ar ratio. Knowing that the relative age of the till is older than the flow below but younger than the flow above, we can bracket the till age. Thus, we know the Sherwin Till is younger than the 3.2 million year old basalt flows as seen at Owens Gorge. We also know the till must be older than the overlying 730,000 year old Bishop Tuff. Continue northbound on US 395.

7.5: Turn left from US 395 onto McGee Creek Road.

1.3, STOP 2.4: We are standing on the sharp crest of a lateral moraine of Tahoe age (figure 19). Glacial ice filled the valley to at least this level during the Tahoe and possibly Tioga glaciations. To the north we have a good view of Lake Crowley and Long Valley. Lake Crowley, now man-made, was 300 feet deep during glacial times. Shorelines of glacial Long Valley Lake can be seen at about the 7,000 foot elevation.

Long Valley is completely bounded by faults in a semicircular pattern and filled with more than 10,000 feet of sediment. Geophysical and hydrothermal evidence suggest the collapse caldera is underlain by a shallow intrusive body. Eruptions of rhyolite and basalt subsequent to the caldera collapse of 730,000 years ago have formed a resurgent dome surrounded by several "moat" flows (Bailey, 1989).

Long Valley keeps us on our toes by periodic earthquake swarms in the Mammoth Lakes area. During the early '80s, the USGS become very concerned about earthquakes and rapid uplift within the caldera, fearing another eruption was imminent. In May, 1980, a sequence of damaging M 6 earthquakes was accompanied by nearly two feet of uplift in the resurgent dome area (Bailey, 1989). Since then Long Valley has quieted down, although micro-earthquake swarms continue. On May 6-7, 1990, a swarm of 300 earthquakes occurred over a 24 hour period, the largest measuring M 3.5. This activity suggests that magma is moving around in a chamber beneath the resurgent dome.

0.8, STOP 2-5: Turn left into the campground. A spectacular fault scarp offsets the glacial moraines here (figure 20). The base of the 50 foot high scarp is at grove of trees near the south end of the campground.

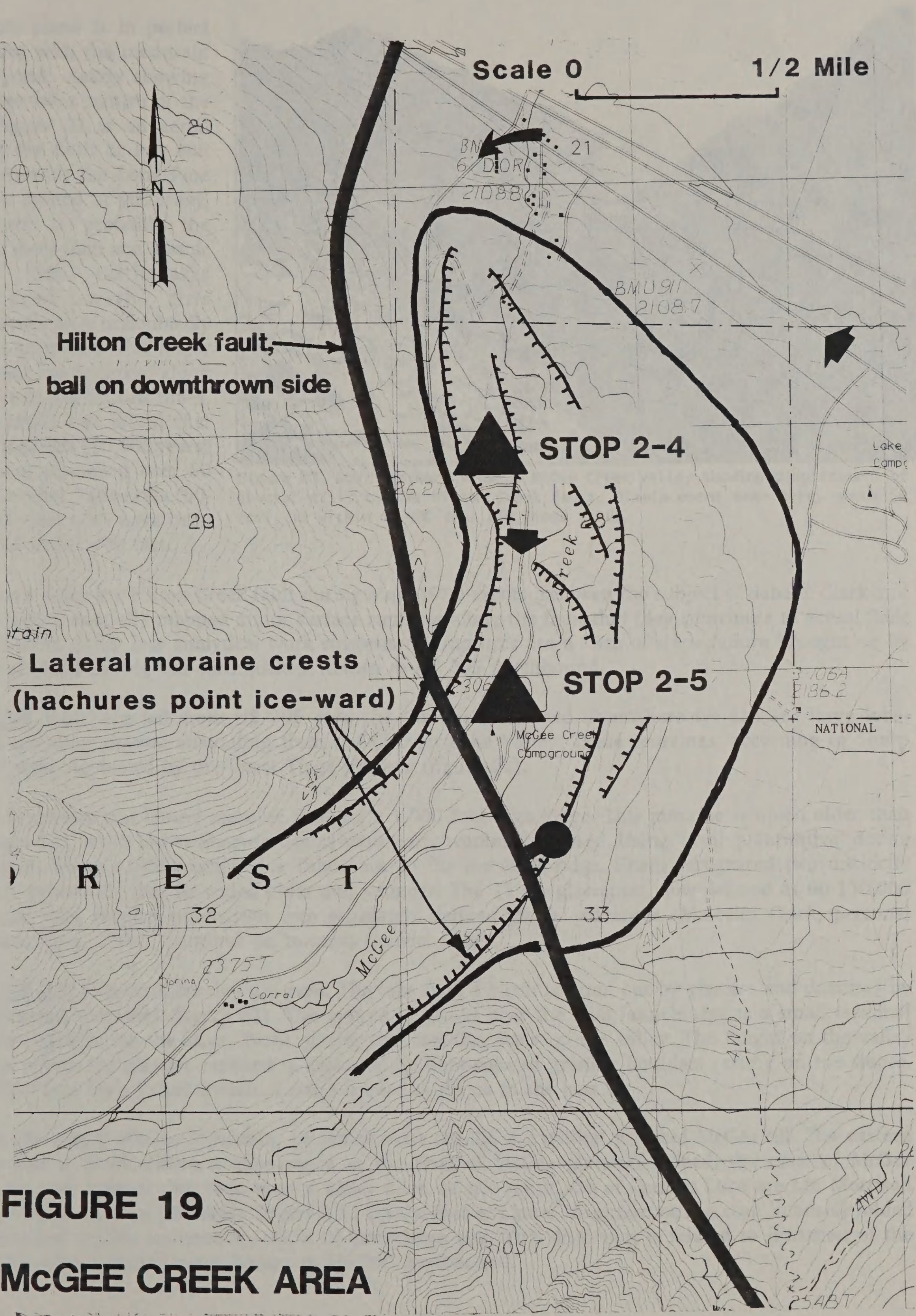


FIGURE 19

McGEE CREEK AREA

The fault plane is in perfect alignment with the mountain face beyond, clearly showing the range front nature of the fault. Figure 21 is an aerial view of the fault at low sun angle. As with the Lone Pine fault we looked at yesterday, this scarp is probably the result of more than one seismic event. The earthquakes associated with this displacement were undoubtedly large in magnitude. No major movement has occurred along this fault during historic times. Clark (1981) has found that latest Tioga tills (10,000 years) have been displaced over 50 feet. The older Tahoe tills (60-130,000 years old) have been displaced about 400 feet.

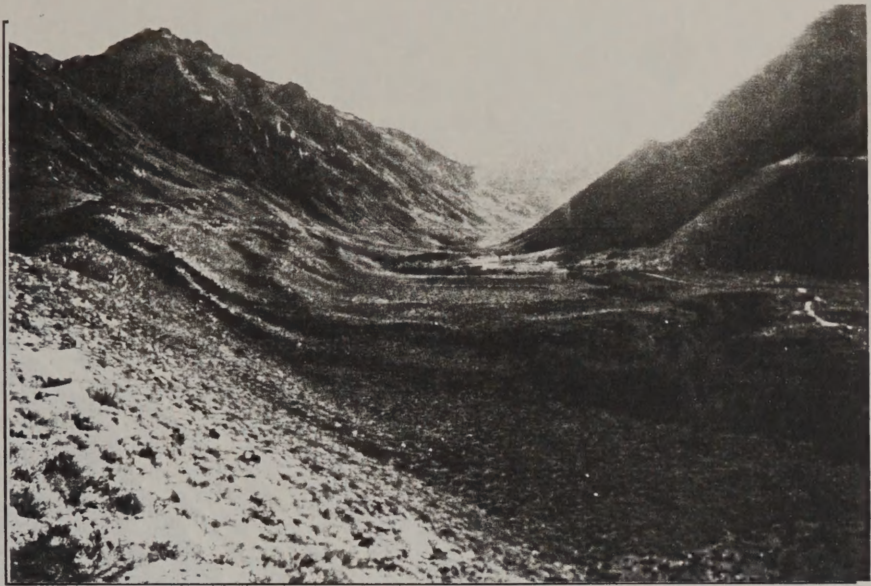


**Figure 20.** Southwestward view up McGee Creek valley showing displacement of glacial tills by the Hilton Creek fault. Displacement seen here, about 50 feet, is within 10,000 year old Tioga tills.

Movement along the Hilton Creek fault during May, 1980 events has been the subject of debate. Clark and others (1980) carefully mapped minor surface ruptures along the fault that they contribute to actual fault displacement. Other less analytical work suggests the ruptures are a form of slope failure brought on by ground shaking during the earthquakes. Return to US 395 northbound.

4.1, STOP 2-6: Turn left from US 395 onto the Convict Lake road. From here we can see large lobe-shaped morainal masses emanating from the Convict Lake Valley. These moraines, according to Sharp (1965), were deposited by the latest Tioga glaciers (figure 22).

To the southeast is a lateral moraine forming a 1,000 foot high ridge. This moraine is much older than Tioga age, but not as old as Sherwin age as some early workers proposed. Using "semi-quantitative" dating techniques, Sharp (1965) assigned a Tahoe age to the morainal ridge. Sharp recognized two distinctly different Tahoe tills that he called older and younger. The Tahoe glaciation, now defined as 60-130,000 years old, may require subdivision into separately defined glacial advances (Malcolm Clark, personal communication, 1990). Continue on towards Convict Lake.

2.6, STOP 2-7: Convict Lake day use area. The lake is in a basin scoured out by glaciers and dammed by their terminal moraines (figure 23). The mound of gravel near the boat launch area is a small terminal moraine deposited as the latest Tioga glacier was receding back up the valley. The height on the valley walls to which the glaciers reached is indicated by light-colored granitic boulders resting on the slopes. The 1,000 foot high Tahoe morainal ridge towers above us to the east.

Also to the east is McGee Mountain, on which rests the 2.5-3.2 million year old McGee till. The eastern Sierras had a much different appearance at the time of McGee glaciers. Indeed, the crest of McGee Mountain may have at that time been a valley floor. At the south end of Convict Lake are Mt. Morrison (to the left) and Laurel Mountain (figure 23). On the face of Laurel Mountain can be seen intensely folded and distorted marine sedimentary rocks of Ordovician age. This distortion is related to intrusion of the Sierra Nevadan granitic rocks. Return to US 395 northbound.

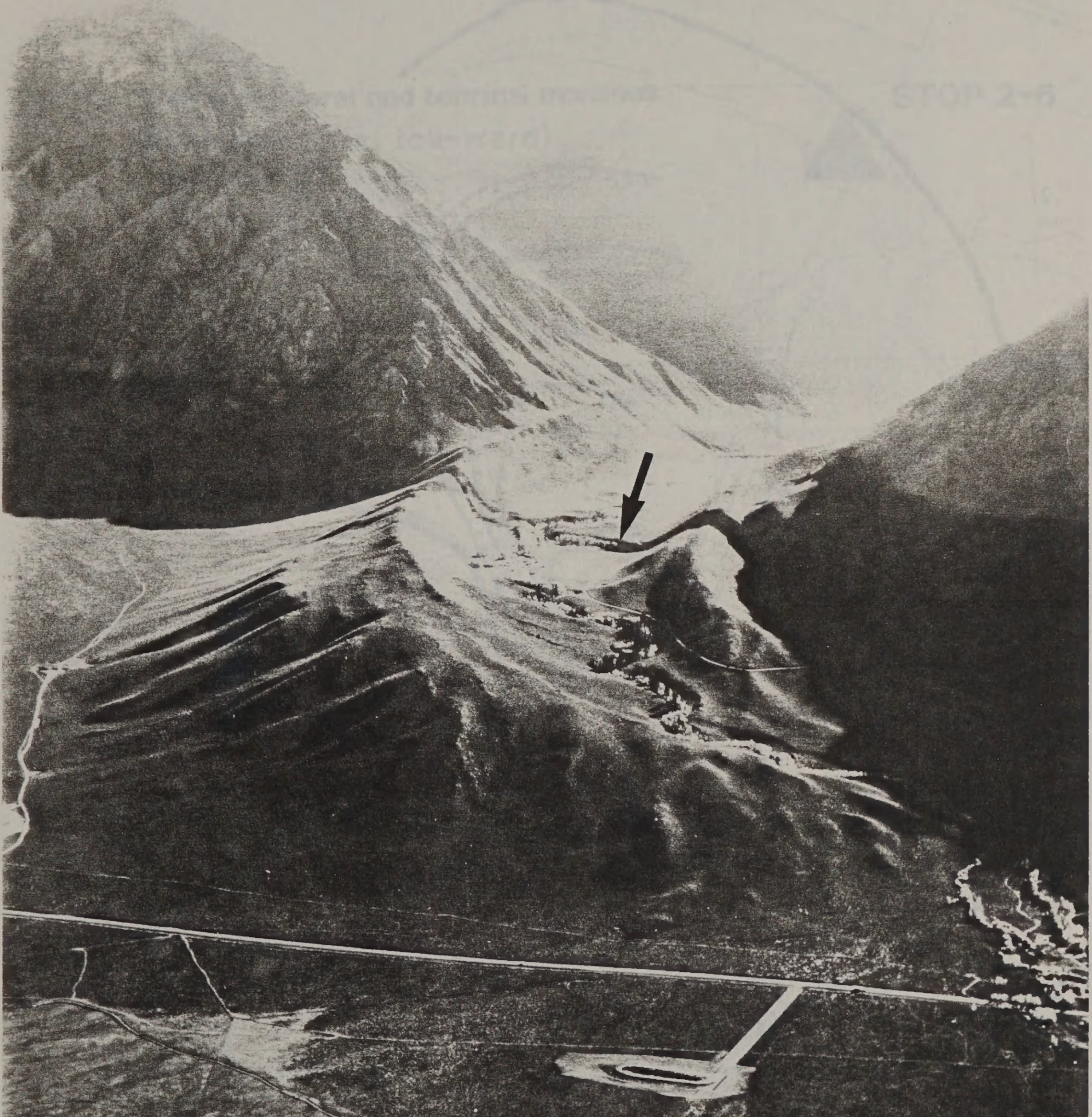
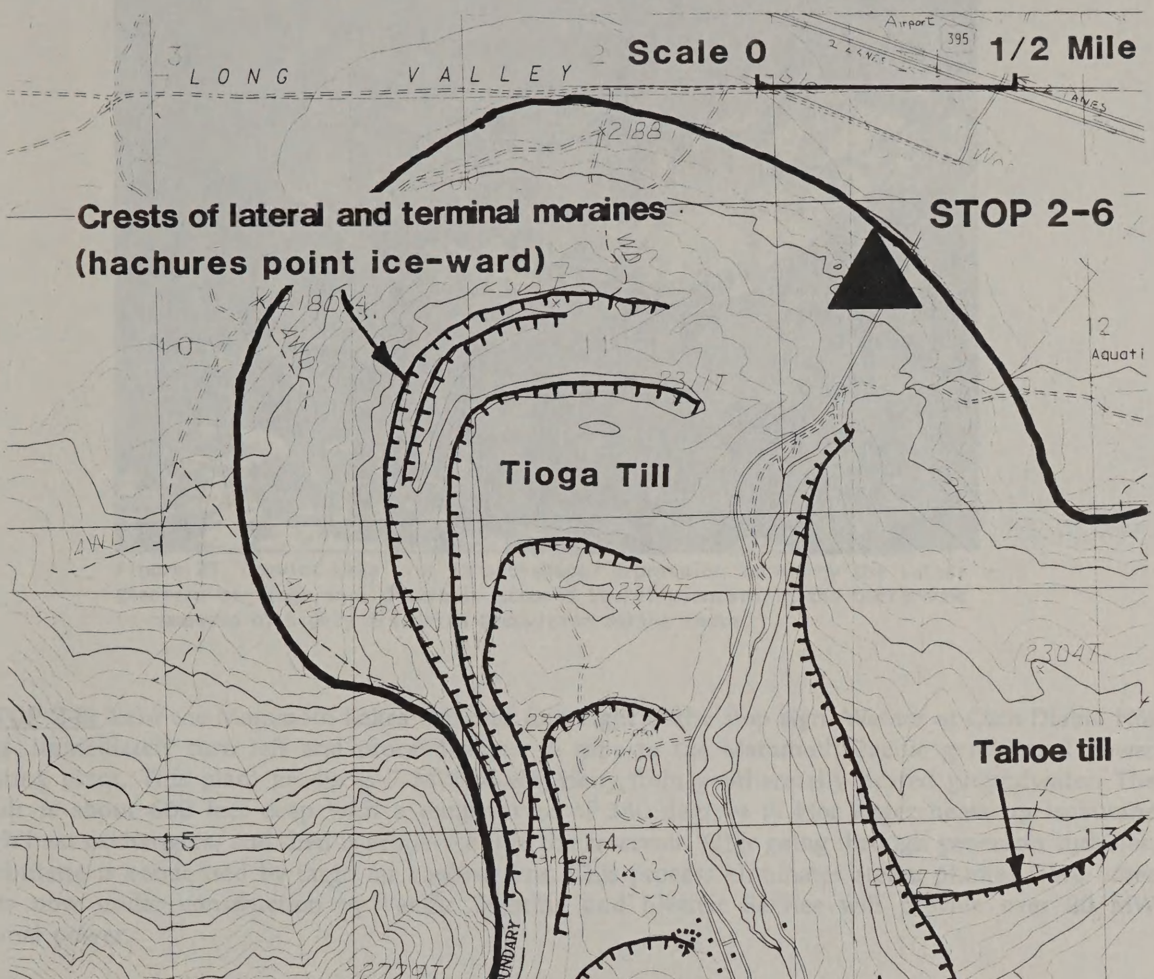


Figure 21. Fault scarp offsetting Tahoe age glacial moraines along McGee Creek. The scarp is about 60 feet high and aligns perfectly with the Sierran range front.



# FIGURE 22

# MORAINES OF THE CONVICT LAKE AREA

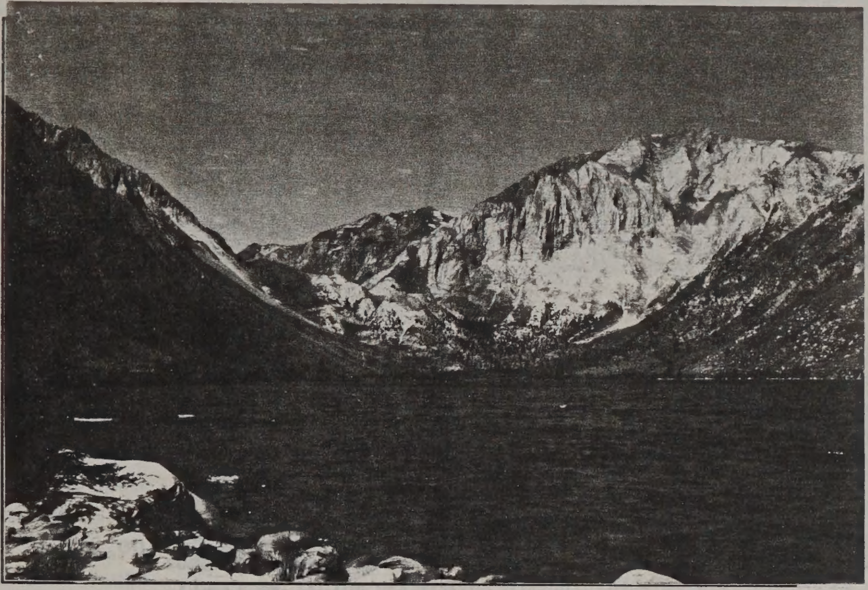


**Figure 23.** Convict Lake lies in a U-shaped depression carved by the latest glaciers of Tioga age. Glacially scoured Laurel Mountain in the background is composed of highly distorted Ordovician marine rocks.

__4.3, STOP 2-8:__ Take the Mammoth Lakes exit and turn right at the stop sign. We are at Casa Diablo Hot Springs. Immediately turn left and proceed about ¼ mile to the Mammoth Pacific geothermal power generating plant. This plant produces 7 MW of electricity from geothermally heated groundwater. The reservoir is about 600 feet deep with a temperature of 340 degrees F. Hot water heats up isobutane through heat exchangers, and then is reinjected into the reservoir. After going through generator turbines, the isobutane is condensed by large air cooling fans. This process eliminates steam plumes. Two other projects now under construction by Pacific Lighting and Electric Service will provide over 20 MW additional power.

Return to Route 203 toward Mammoth Lakes. As we approach Mammoth Lakes, notice the black basalt outcrops near the road. These lava flows are 200-300,000 years old. They rest upon Casa Diablo glacial till estimated to be 400-500,000 years old (Sharp, 1976). Proceed through downtown Mammoth Lakes. The current power output of the Mammoth Pacific plant, 7 MW, would provide only 1/3 of this town's electrical needs.

__3.2:__ Turn right onto Old Mammoth Road (Route 203).

__0.9:__ Turn left onto Minaret Road (Route 203).

__1.9, STOP 2-9:__ Earthquake Fault. The name of this fissure is misleading, for it is neither a fault nor associated with known earthquake activity. It is an open crevice in a lava flow that has split apart laterally. This type of displacement is not normally associated with faults. The crevice is deep enough to trap snow in the bottom year-round. Continue west on Minaret Road past the Mammoth Lakes ski area.

__4.0, STOP 2-10:__ Minaret Vista. Turn right into the Minaret Summit parking area. Below us is the deeply glaciated valley of the Middle Fork of the San Joaquin River. This river formerly drained large areas to the east. But uplift along Sierran frontal faults within the past 3 million years (Bailey, 1989) has beheaded the stream from its eastern beginnings. On the western horizon are the Minarets, Mt. Ritter, and Banner Peak. This range is composed of various types of metamorphosed volcanic rocks of Cretaceous age that weather to crags and spires (figure 24).

The volcanics were originally part of a caldera similar to Long Valley. This caldera, however, was located in an oceanic island arc setting (Bailey, 1989).

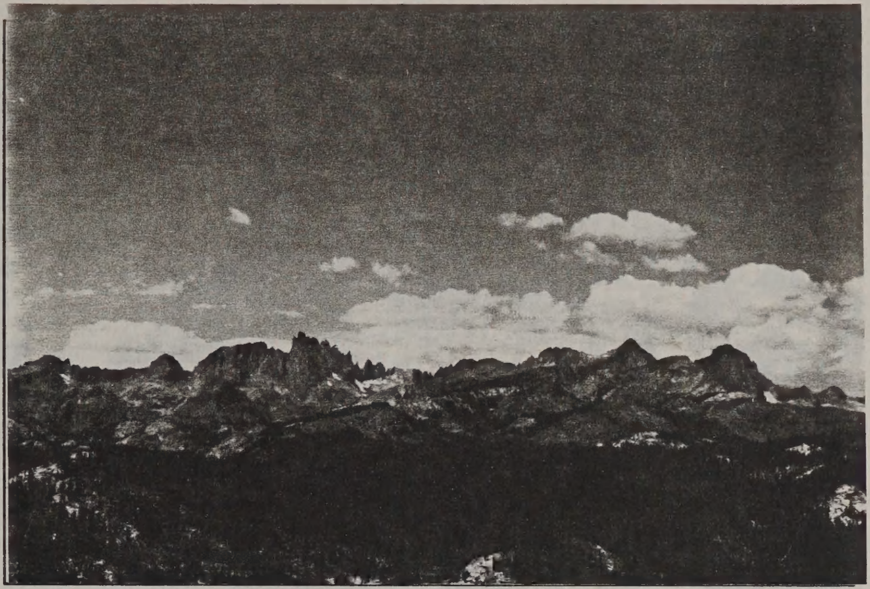


Figure 24. On the western horizon are the Minarets. The rocks composing these mountains are various types of metamorphosed volcanic rocks of Cretaceous age that weather to crags and spires.

To the north of Minaret Vista, San Joaquin Ridge is composed of 2.2-3.6 million year old volcanic rocks (Bailey, 1989). To the southeast is Mammoth Mountain, covered with ski lifts (figure 25). This volcano sits on the rim of Long Valley caldera (figure 14) and post-dates the caldera collapse. The oldest volcanic rocks on Mammoth Mountain are 400,000 years old (Sharp, 1976). The volcano is currently dormant. Micro-earthquake swarms below the mountain and steam vents on its flanks remind us that it could reawaken at any time. Emissions of gas and steam result in a semi-permanent cloud over the mountain during winter. Continue on towards Devils Postpile National Monument.

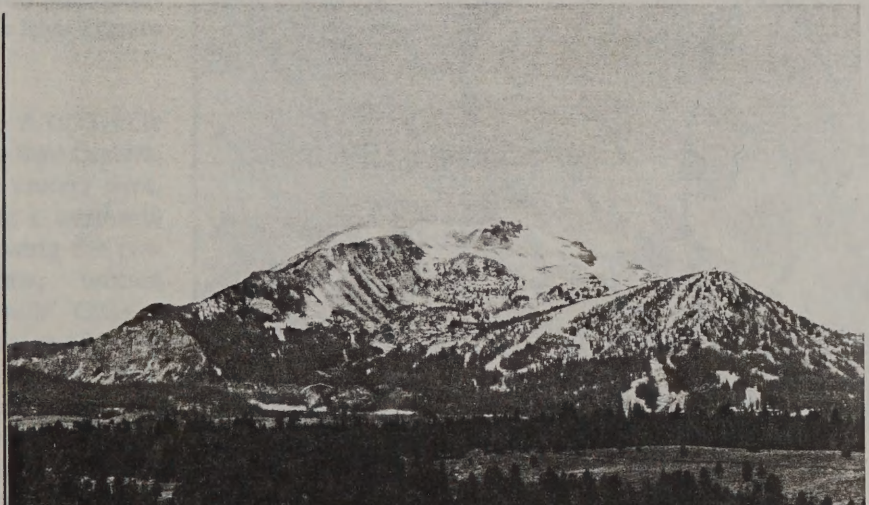


**Figure 25.** Mammoth Mountain is a collection of volcanic rocks erupted during the past 400,000 years (post Long Valley caldera collapse). Steam fumaroles and micro-earthquake swarms below suggest the volcano is only sleeping.

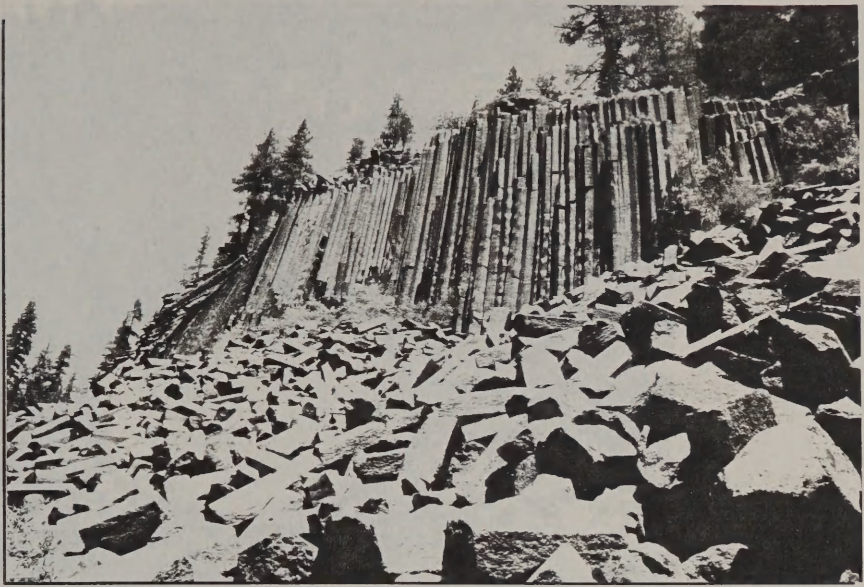


Figure 26. Columnar basalt of Devils Postpile. Several columns fell during the May, 1980 earthquake activity.

14.5, STOP 2-11: Devils Postpile National Monument is in the valley of the Middle Fork of the San Joaquin River. A short walks brings us to the "postpile," a spectacularly columnar-jointed basalt flow (figure 26). The very long, well-formed columns of this flow are related to how the flow cooled. Bailey (1989) suggests ponding (and slow cooling) of the lava flow behind a glacial moraine.

The age of the basalt flow is 100-200,000 years (Baily, 1989). Since then, the valley has been glaciated several times, the latest being Tioga. Evidence for ice overriding the basalt flow can be seen by a short hike to the flow top. The top of the flow has been polished and striated by the heavy, rock debris-laden glacier (figure 27). After lunch, return towards Mammoth lakes on Route 203.

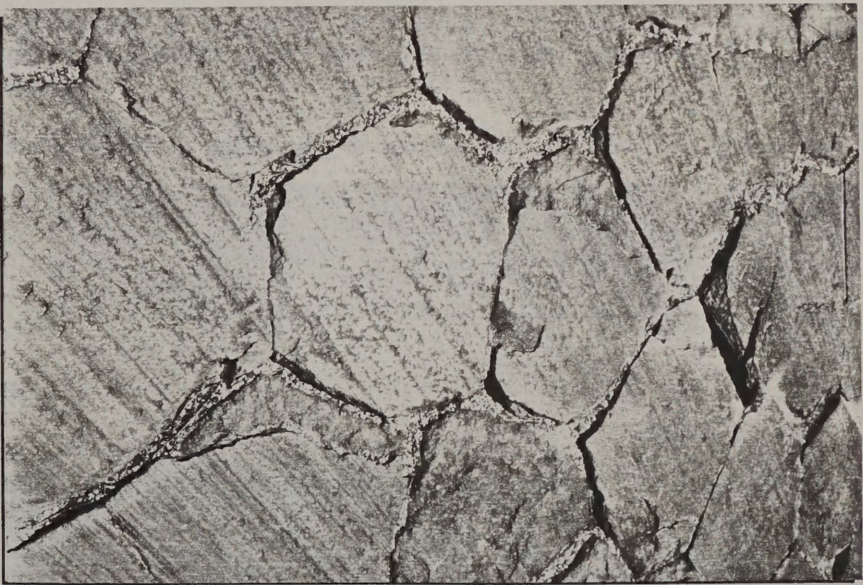


Figure 27. Glacially polished and striated basalt column tops at Devils Postpile.

11.6: Turn left from Route 203 onto Mammoth Scenic Loop.

2.7: Turn left from Mammoth Scenic Loop onto Inyo Craters Road.

1.3, STOP 2-12: A 0.25 mile walks takes us to Inyo Craters. There are three craters here, all aligned along a northerly axis. We are viewing the two southerly craters, termed "North" and "South" Craters. These pits are about 600 feet in width and 180 feet deep. The craters (figure 28) are the result of phreatic explosions; rising molten rock contacted groundwater, causing tremendous steam explosions. The three explosions occurred at about the same time, probably within hours or days (Baily, 1989). An age of about 710 years for the craters is based on age-dating a shattered log in South Crater. This date is near the time Columbus discovered America.

Notice the color difference in the water between the two pits. Bailey (1989) attributes the yellowish color of South Crater to suspended sulfur. The lake in North Crater is colored brown by organic debris. Return to Mammoth Scenic Loop, eastbound.

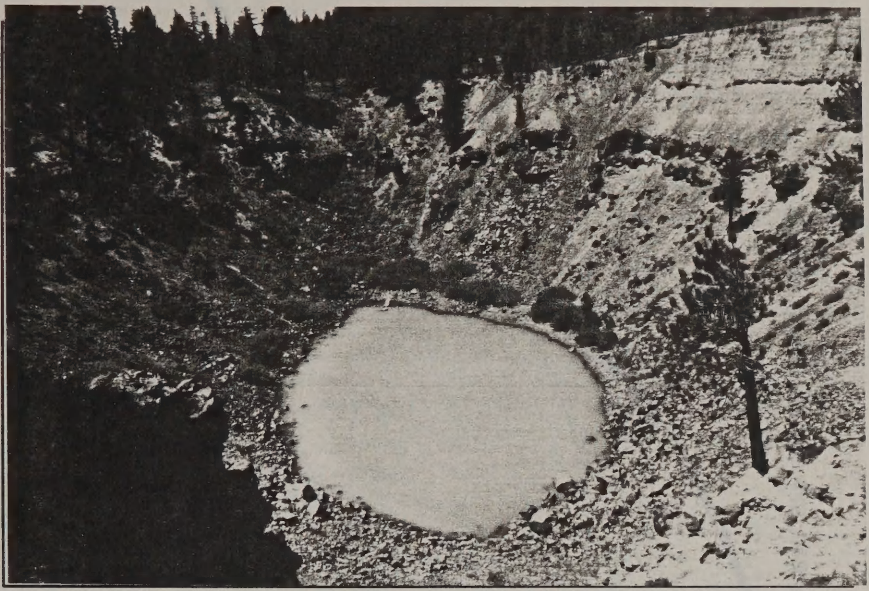


**Figure 28.** South Crater is one of three phreatic explosion craters termed Inyo Craters. The craters formed about 700 years ago when rising molten rock contacted groundwater, causing great steam explosions.

3.2: Turn left from Mammoth Scenic Loop onto US 395 northbound.

4.0: Crestview. US 395 begins climbing out of the north rim of Long Valley caldera. As we proceed northward, note the very fresh appearing obsidian domes (Inyo Domes) to the west of US 395. These eruptions occurred about 600 years ago.

6.7: We are now entering Mono basin. US 395 is following a drainage in our old friend, the Bishop Tuff.

3.2: Off to the east are Mono Craters (figure 29). The "craters" are actually rhyolitic domes ranging in age from 35,000 to 600 years (figure 30). The domes are aligned roughly north-south along a semicircular trace. This "ring fracture" pattern suggests the possibility of another caldera similar to Long Valley. If so, Mono Craters would be on the eastern rim of the caldera.

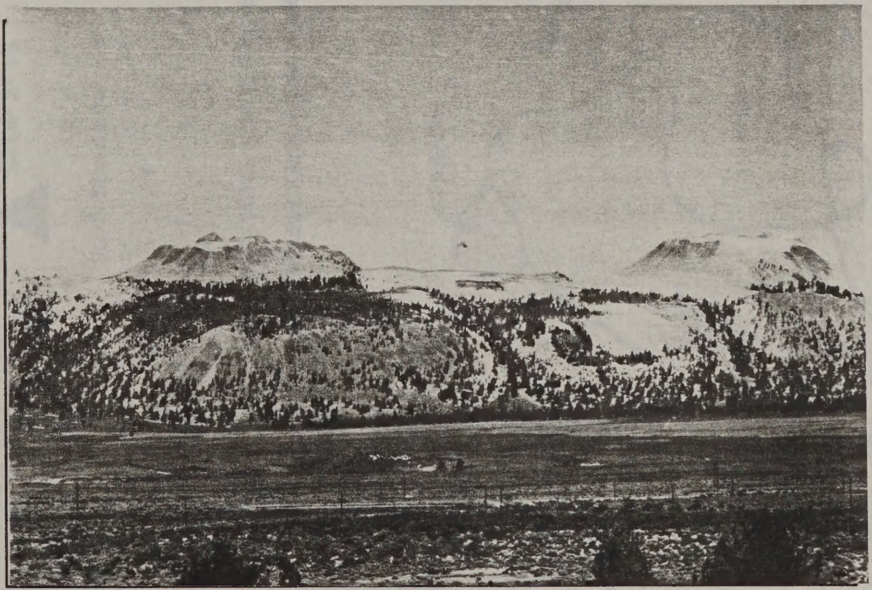
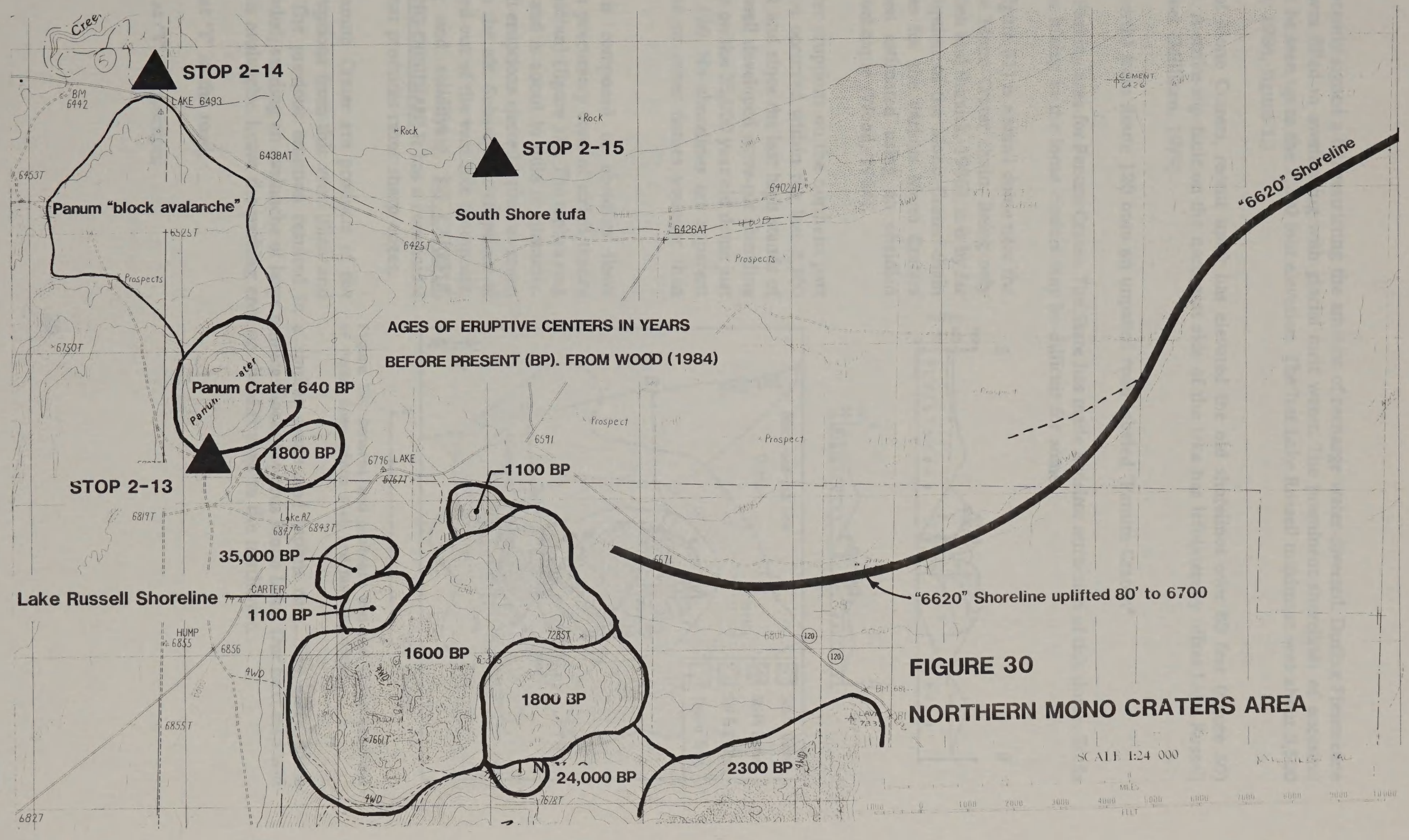


**Figure 29.** Mono Craters are a series of rhyolitic domes erupted along a semi-circular fracture zone. Ages range from 35,000 to 600 years.

1.2: Turn right from US 395 onto Route 120 eastbound. To the north is Mono Lake. Like Owens Lake, Mono Lake has shrunk considerably since the turn of the century due to diversion of feeding tributaries to the Los Angeles aqueduct. Much controversy has been raised over the issue of a declining Mono Lake. At low water levels a land bridge allows predators access to Negit Island and migratory bird colonies.



AGES OF ERUPTIVE CENTERS IN YEARS BEFORE PRESENT (BP). FROM WOOD (1984)

FIGURE 30

NORTHERN MONO CRATERS AREA

The Governor recently signed a bill restricting the amount of recharge water diverted. During Pleistocene time the basin was filled to overflowing with glacial melt water. The prominent shorelines of ancestral Lake Russell can be seen up to the 7,200 foot elevation. The last Lake Russell maximum was about 3,500 years ago (Stine, 1984, figure 1.)

In the vicinity of Mono Craters, recent uplift has elevated the old shorelines over 80 feet (figure 30) (Milliken, 1979). A strike-slip fault on the northeast side of the lake has left-laterally offset Lake Russell shorelines 800 feet (Milliken, 1979).

3.1: Turn left (north) from Route 120 onto an unpaved road labeled "Panum Crater."

0.9, STOP 2-13: Parking area for Panum Crater. The State has made a visitor attraction of this dome. Trails are provided, but hiking in the loose cinders may be difficult for some.

Panum Crater (figure 31) is a small dome near the north end of the Mono Crater chain. Being only 600 years old (Sieh and Bursick, 1986), it is by far the youngest eruption of the Mono Crater chain (figure 30). Ages for the various Mono Craters domes have been estimated using an obsidian hydration rind technique (Wood, 1984).

Most Mono Crater eruptions on the northern part of the chain have occurred within the last 2,300 years (figure 30) and since the last high stands of Lake Russell. A well developed wave-cut shoreline is visible high up on the 35,000 year old dome just south of Route 120. No shorelines are apparent on Panum Dome or other domes younger than 2,300 years.

Panum Dome is composed of obsidian flows surrounded by a precursory cone of airfall tephra (pumice and obsidian) (figure 31). The tephra ring is cone shaped and is about ½ mile in diameter. Precursory airfall eruptions ejected tephra as much as one mile into the air. Subsequent eruptions of obsidian squeezed out of the vent like toothpaste, quickly cooling and solidifying. **BE CAREFUL WHEN HANDLING OBSIDIAN!** It has a conchoidal fracture habit that produces razor sharp edges.

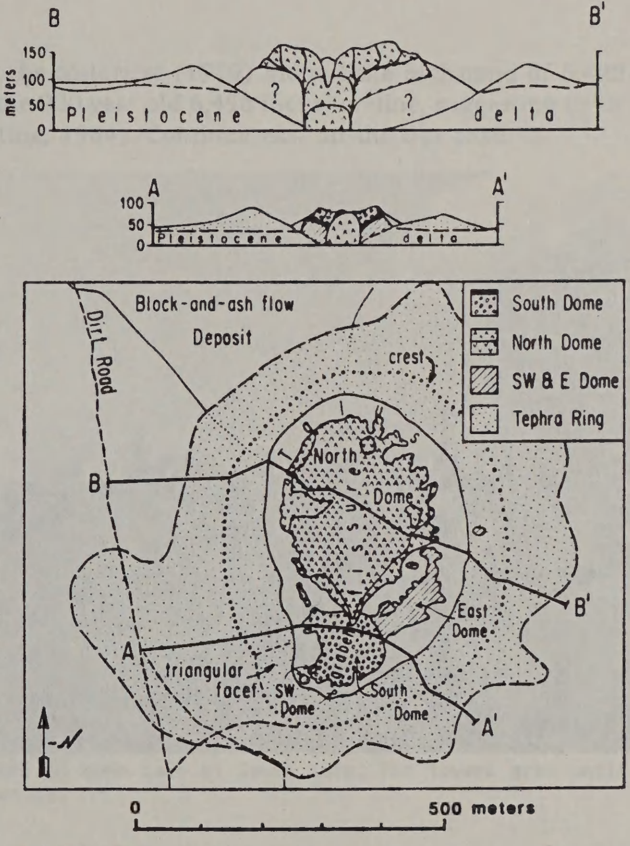


Figure 31. Generalized geologic map and cross sections of Panum Dome (from Sieh and Bursik, 1986).

The rocks of Panum Crater are products of the latter of two eruptions from this vent (Sieh and Bursik, 1986). The previous eruption resulted in a similar dome and tephra ring. The early dome apparently exploded, sending an avalanche of large pumice blocks towards Mono Lake. Our next stop will be to look at this avalanche. Leave the parking area on the dirt road to the northwest.

1.3: Bear right at "Y" in the road.

0.7: Turn right at "T" intersection.

0.4, STOP 2-14: Toe of the block avalanche. Carved into the avalanche is a wave-cut bench covered with well-rounded beach cobbles. Elevation of the bench is 6,456 feet. Since no wave-cut benches occur higher than this on the 600 year old avalanche, we can assume this elevation is the highest lake level reached during the past 600 years (Stine, 1984). The 6,456 foot lake level, radiocarbon dated at about 220 years, is the highest elevation reached by the lake during the preceding 2,000 years (Stine, 1984).

From this location we get good views of Paoha and Negit Islands. Negit is composed chiefly of volcanic cones and flows (Stine, 1984) that predate the 220 year-old 6,456 foot lake highstand (Stine, 1984). One small flow on the island lacks the 6,456 foot shoreline, hinting an age less than 220 years (Stine, 1984).

Paoha Island is composed of uplifted lake bed sediments, possibly related to a shallow intrusive body. The arched nature of the uplifted strata is apparent if the light is right. High temperature thermal springs near the island led to geothermal exploration in the 1970s. An exploration well was slant-drilled toward the island from the south shore in the hopes of confirming a shallow intrusive. No abnormal temperature gradients were found in the well.

Paoha Island has a wave-cut shoreline representing the historical (1919) Mono Lake highstand of 6,428 foot elevation. However the island lacks evidence of the 220 year old 6,456 foot shoreline, suggesting uplift occurred between the late 1700s and late 1800s (Stine, 1984). Continue east on the dirt road.

1.6, STOP 2-15: Turn into the South Tufa parking area. A short walk brings us to the shore of Mono Lake and an abundance of tufa towers (figure 32). Having had no outlet since glacial (Lake Russell) times, the lake has shrunk from its glacial maximum largely due to evaporation. As a result, the water has become increasingly saline. Ground water flows into the lake from lake-bottom springs. Carbonates ($CO_3$) in the lake water combine with calcium (Ca) in groundwater to form calcium carbonate ($CaCO_3$, the same composition as limestone). The towers grow until they reach the lake surface.

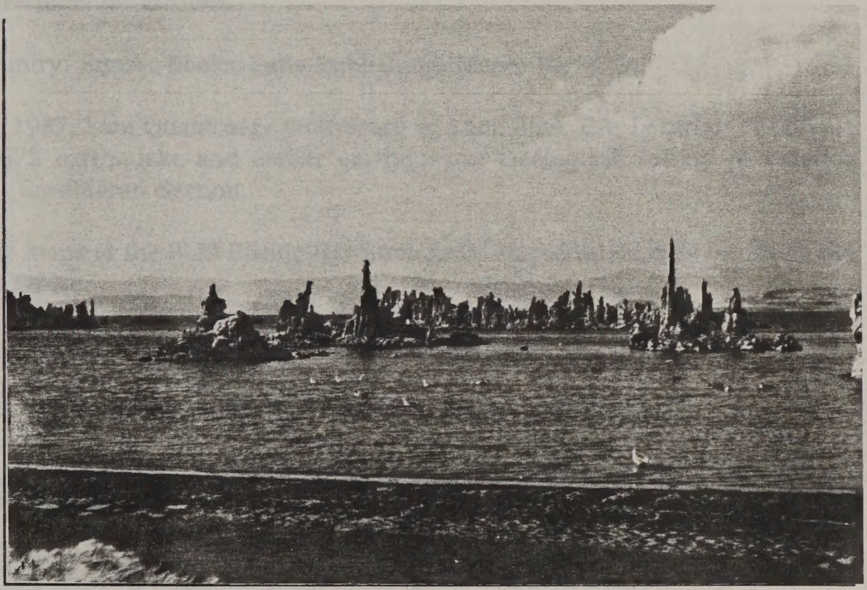


**Figure 32.** Tufa towers in Mono Lake at South Tufa. The towers grew until reaching the lake surface.

The large number of towers at roughly equal height suggest a long period of lake level stability. After the ice age, Lake Russell evaporated rapidly due to its large surface area. Recharge could not keep pace with water lost to evaporation. As the lake level dropped, its surface area decreased, reducing the rate of evaporation. Gradually an equilibrium was reached between recharge and evaporation. Prior to this century the lake level stabilized for a long period of time allowing tufa towers to flourish.

This stop is the end of our field trip for this time. If you have further questions about the natural resources unique to the eastern Sierra Nevada region, please contact local offices of the Bureau of Land Management and U.S. Forest Service. Thank you for your participation.

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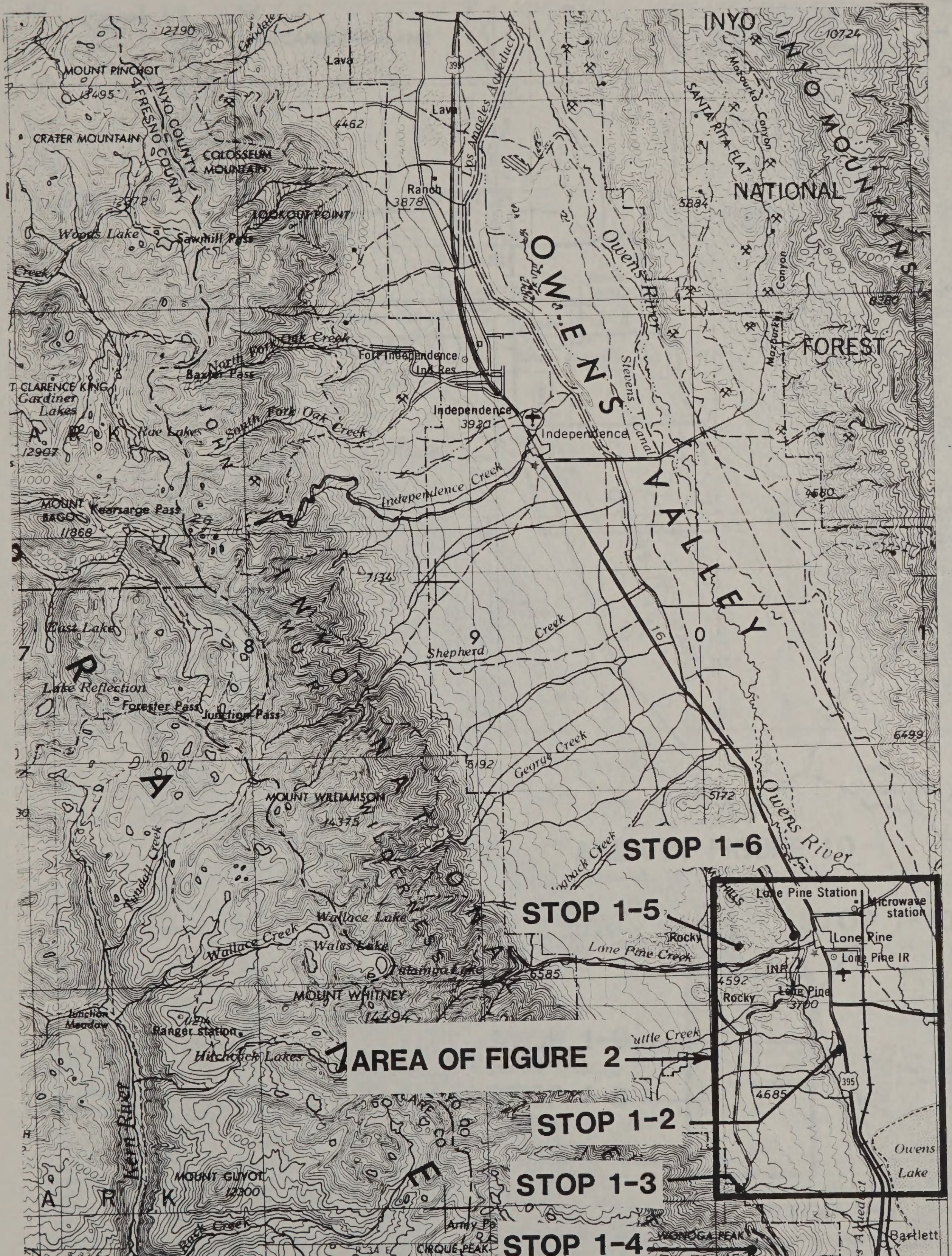
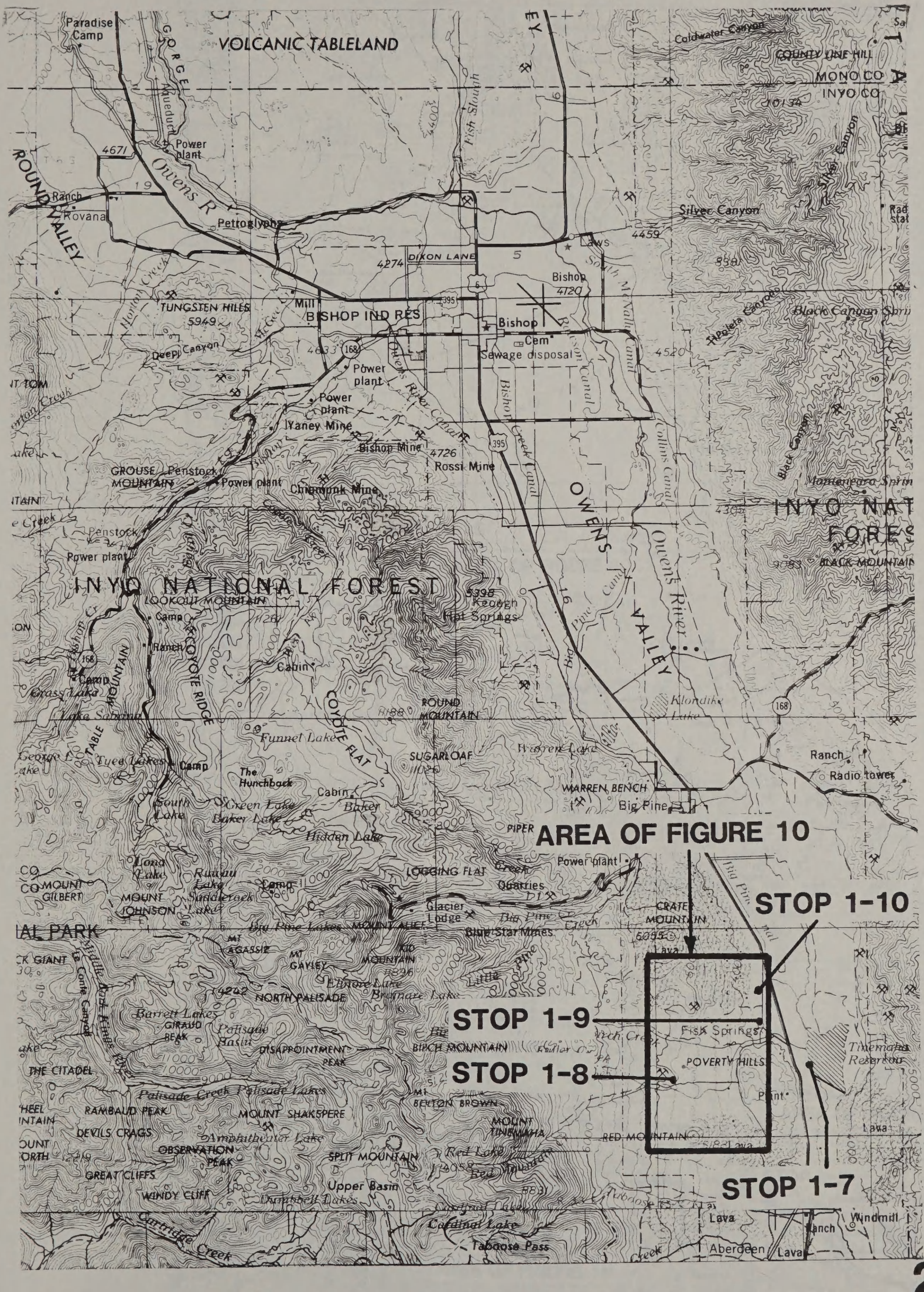
# APPENDIX

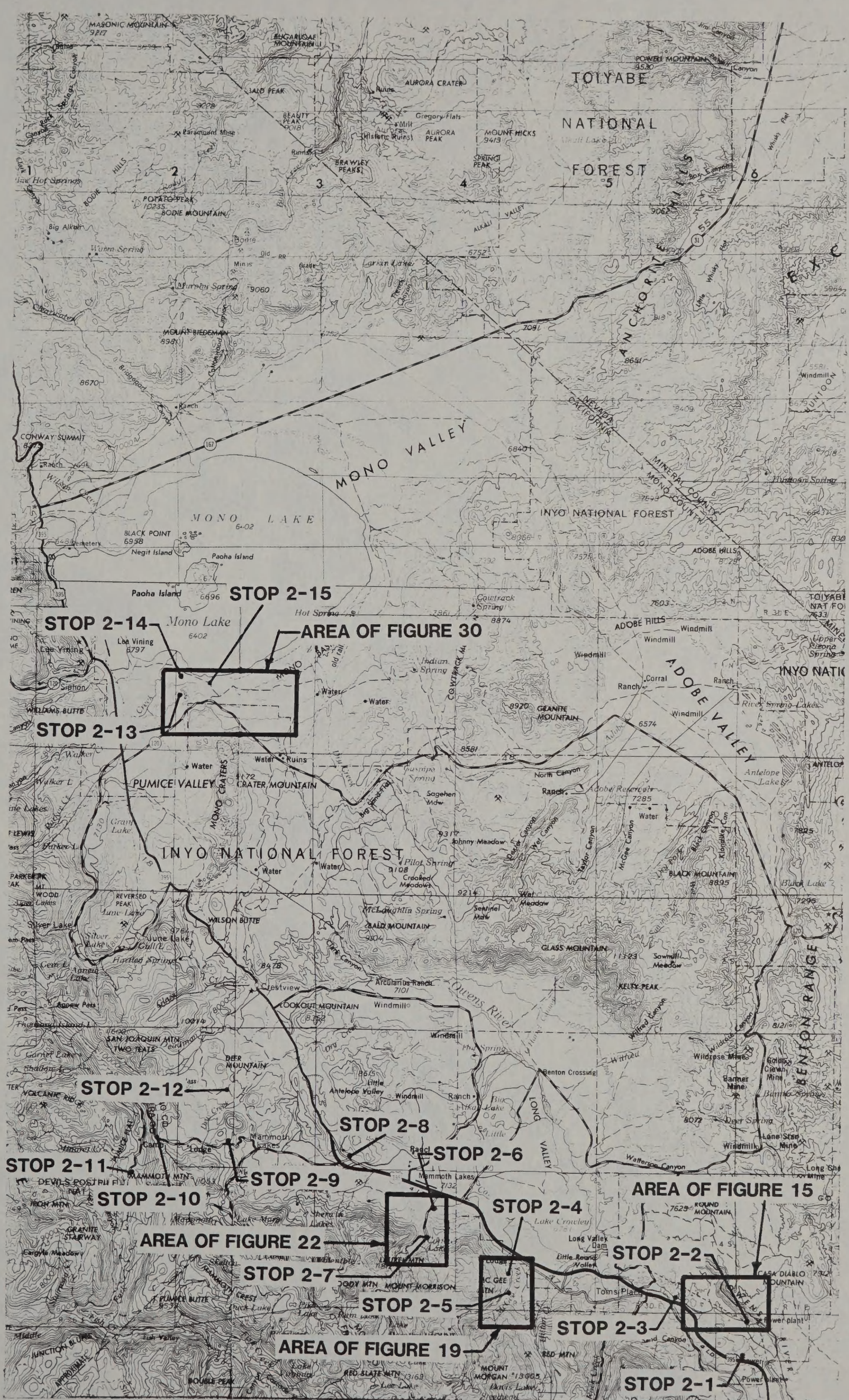
| Subdivision in use by the U.S. Geological Survey | | | Age estimates commonly used for boundaries (in m.y.) | |
|---|---|---|---|---|
| Era or Erathem | System or Period | Series (Epoch) | | |
| Cenozoic | Quaternary | Holocene (Holocene) | | |
| | | Pleistocene (Pleistocene) | | 1.8 |
| | Tertiary | Pliocene (Pliocene) | | 5.0 |
| | | Miocene (Miocene) | | 22.5 |
| | | Oligocene (Oligocene) | | 37.5 |
| | | Eocene (Eocene) | | 53.5 |
| | | Paleocene (Paleocene) | 65 | 65 |
| Mesozoic | Cretaceous [1] | Upper (Late)<br>Lower (Early) | 136 | |
| | Jurassic | Upper (Late)<br>Middle (Middle)<br>Lower (Early) | 190–195 | |
| | Triassic | Upper (Late)<br>Middle (Middle)<br>Lower (Early) | 225 | |
| Paleozoic | Permian [1] | Upper (Late)<br>Lower (Early) | 280 | |
| | Pennsylvanian [1] | Upper (Late)<br>Middle (Middle)<br>Lower (Early) | [2] 320 | |
| | Mississippian [1] | Upper (Late)<br>Lower (Early) | 345 | |
| | Devonian | Upper (Late)<br>Middle (Middle)<br>Lower (Early) | 395 | |
| | Silurian [1] | Upper (Late)<br>Middle (Middle)<br>Lower (Early) | 430–440 | |
| | Ordovician [1] | Upper (Late)<br>Middle (Middle)<br>Lower (Early) | 500 | |
| | Cambrian [1] | Upper (Late)<br>Middle (Middle)<br>Lower (Early) | 570 | |
| Precambrian | Precambrian Z [3] | | 600 | |
| | Precambrian Y [3] | | 1,600 | |
| | Precambrian X [3] | | 2,500 | |
| | Precambrian W [3] | | | |


STOP 1-6
STOP 1-5
AREA OF FIGURE 2
STOP 1-2
STOP 1-3
STOP 1-4
OWENS VALLEY
INYO NATIONAL FOREST
INYO MOUNTAINS
MOUNT PINCHOT
CRATER MOUNTAIN
INYO COUNTY
FRESNO COUNTY
COLOSSEUM MOUNTAIN
LOOKOUT POINT
Woods Lake
Sawmill Pass
Baxter Pass
North Fork Oak Creek
South Fork Oak Creek
Rae Lakes
CLARENCE KING
Gardiner Lakes
MOUNT BAGO
Kearsarge Pass
East Lake
Lake Reflection
Forester Pass
Junction Pass
MOUNT WILLIAMSON
14375
Wallace Lake
Wallace Creek
Wales Lake
Tulainyo Lake
MOUNT WHITNEY
14494
Junction Meadow
Ranger station
Hitchcock Lakes
Kern River
MOUNT GUYOT
12300
Rock Creek
Ranger Station
Army Pass
CIRQUE PEAK
WONOGA PEAK
Lava
Ranch
3878
Los Angeles Aqueduct
Owens River
Stevens Canal
Fort Independence
Independence
3920
Independence Creek
Shepherd Creek
George Creek
Lone Pine Creek
Lone Pine Station
Microwave station
Lone Pine
Lone Pine IR
3700
Rocky
4592
4685
Owens Lake
Bartlett
SANTA RITA FLAT
Mazourka Canyon
395
12790
13495
4462
12872
5884
10724
8380
4680
6499
5172
5192
7134
6585
12907
11868
1985
R 34 E
R 33 E

1


AREA OF FIGURE 10
STOP 1-10
STOP 1-9
STOP 1-8
STOP 1-7
VOLCANIC TABLELAND
Paradise Camp
GORGE
Aqueduct
Power plant
Owens R
ROUND VALLEY
Ranch
Rovana
Petroglyphs
Fish Slough
Coldwater Canyon
COUNTY LINE HILL
MONO CO
INYO CO
Silver Canyon
Laws
DIXON LANE
Bishop
4120
TUNGSTEN HILLS
5949
Mill
BISHOP IND RES
Cem
Sewage disposal
Deep Canyon
Power plant
Yaney Mine
Bishop Mine
Rossi Mine
Black Canyon
Tinemaha Reservoir
GROUSE MOUNTAIN
Penstock
Power plant
Chipmunk Mine
OWENS VALLEY
Owens River
INYO NATIONAL FOREST
BLACK MOUNTAIN
LOOKOUT MOUNTAIN
Keough Hot Springs
COYOTE RIDGE
COYOTE FLAT
TABLE MOUNTAIN
ROUND MOUNTAIN
Klondike Lake
Funnel Lake
SUGARLOAF
Warren Lake
The Hunchback
WARREN BENCH
Big Pine
Ranch
Radio tower
Green Lake
Baker Lake
Hidden Lake
LOGGING FLAT
Power plant
Quarries
CRATER MOUNTAIN
6095
MOUNT GILBERT
MOUNT JOHNSON
Glacier Lodge
Big Pine Creek
Big Pine Lakes
MOUNT ALICE
Blue Star Mines
MT AGASSIZ
MT GAYLEY
KID MOUNTAIN
NORTH PALISADE
Fish Springs
BIRCH MOUNTAIN
DISAPPOINTMENT PEAK
POVERTY HILLS
THE CITADEL
RAMBAUD PEAK
MOUNT SHAKSPERE
MT BENTON BROWN
MOUNT TINEMAHA
DEVILS CRAGS
OBSERVATION PEAK
SPLIT MOUNTAIN
Red Lake
Red Mountain
RED MOUNTAIN
GREAT CLIFFS
WINDY CLIFF
Upper Basin
Lava
Cartridge Creek
Taboose Pass
Aberdeen
Windmill

2


STOP 2-15
STOP 2-14
AREA OF FIGURE 30
STOP 2-13
STOP 2-12
STOP 2-8
STOP 2-6
STOP 2-11
STOP 2-9
STOP 2-10
STOP 2-4
AREA OF FIGURE 15
AREA OF FIGURE 22
STOP 2-2
STOP 2-7
STOP 2-5
STOP 2-3
AREA OF FIGURE 19
STOP 2-1
TOIYABE NATIONAL FOREST
MONO VALLEY
MONO LAKE
INYO NATIONAL FOREST
ADOBE VALLEY
PUMICE VALLEY
MONO CRATERS
ANCHORITE HILLS
BENTON RANGE
LONG VALLEY
Owens River
Lake Crowley
Mammoth Lakes
Crestview
Lee Vining
CONWAY SUMMIT
GLASS MOUNTAIN
NEVADA
CALIFORNIA
MINERAL COUNTY
MONO COUNTY